# ACTIVE DEPENDENCY COMPLETION IN ADULTS AND CHILDREN: REPRESENTATIONS AND ADAPTATION

by
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ABSTRACT

This dissertation investigates the effect of language experience on syntactic predictions during real time language processing, and how these predictions develop. In particular, it focuses on filler-gap dependency processing. A prominent psycholinguistic theory suggests that incremental processing decisions are governed by statistics derived from the distribution of structures in the input. Children are an ideal testing ground for this theory because they are still acquiring this distributional information.

The first part of this dissertation examines children's syntactic predictions during the real time comprehension of filler-gap dependencies. Though adults' active association of the filler with the verb has been robustly demonstrated, visual world eye tracking data reveals that children do not actively complete the dependency at the verb. A probabilistic account of this finding would attribute it to differential experience with gap positions. A corpus analysis of the distribution of gap positions in the input to adults, child-directed speech, and children's spontaneous utterances revealed that this was not the case; adults and children have similar experience with gap positions.

The second part of this dissertation directly manipulates adults' recent language experience to test predictions of the probabilistic parsing model. Two eye tracking during reading experiments revealed that exposure to an improbable gap position can decrease active gap filling at the verb, but it does not increase the likelihood of predicting this alternative structure. A third experiment suggests that these effects may be due to a task-specific processing strategy.

The third part of this dissertation attempts to accelerate the development of active gap filling by manipulating the statistics in children's input. This distribution is provided by a novel picture completion task designed to elicit *wh*-questions. Comprehension of concentrated filler-gap dependency input had no effect on children's syntactic predictions, but production of a less probable gap position primed predictions for the more probable one.

Finally, this dissertation critically evaluates the probabilistic parsing model in light of the experiments reported within and finds that statistical information does not reliably predict parsing behaviors. An alternative model is proposed that accounts for these findings and appeals on the representational requirement imposed by the filler-gap dependency structure.

Primary Reader: Akira Omaki

Secondary Reader: Colin Wilson

Other Committee Members: Steven Gross, Barbara Landau, Kevin Duh

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# Chapter 1 – Introduction

## 1 Overview

This dissertation seeks to assess the effect of language experience on syntactic predictions during real time language processing. Additionally, it examines the development of these predictions. Prediction in language comprehension has been found to be rampant and, therefore, seems to be a fundamental feature of language processing. There are both positive and negative effects of prediction, however. Predictions can be beneficial, because real time sentence comprehension occurs over a very small time window (on the order of hundreds of milliseconds). Verification of a syntactic or lexical prediction likely requires less processing resources than integrating entirely new information into the current parse, which in turn may lead to faster processing. On the other hand, predictions in language comprehension are potentially detrimental given the multiple options for relaying a particular meaning. As there is uncertainty about the structure, it may be considered inefficient to generate a prediction that could be incorrect and trigger a costly revision process.

In light of these potential disadvantages, predictions need to be predominantly accurate. Therefore, experience with language and syntactic structures is likely a significant factor in the generation of predictions. Experience reveals which syntactic structures are common and which are not. Evidence from adult sentence processing is beginning to suggest that there is a relationship between the distribution of structures in the input and predictive processing. This work, however, has been limited in the structures that it examines and as of yet has not been shown to be robust. Additionally, the relationship between language experience and syntactic prediction has yet to be studied in children, who unlike adults are still learning the overall distribution of structures. In this dissertation, I analyze the distribution of structures in the input, directly manipulate language input, and utilize a population with limited experience (i.e., children) to test the role that language experience plays in the development of syntactic prediction. I focus on filler-gap dependencies, and examine the effects of structural probabilities on the prediction of the gap position.

## 2 Prediction and cognition

Recent work has suggested that the brain is fundamentally predictive in nature and thus could be described as a prediction machine (Clark, 2013; Friston, 2010). Given this description, it is unsurprising that prediction has been demonstrated in many cognitive domains including vision (e.g., Bar et al., 2006; Enns & Lleras, 2008; Murray, Schrater, & Kersten, 2004; Yuille & Kersten, 2006; Ullman, 1995; c.f. Firestone & Scholl, in press), the integration of perception and action (e.g., Bubic, von Cramon, & Schubotz, 2010; Clark, 2013; Hayhoe & Ballard, 2005), social cognition (e.g., Frith & Frith, 2006; Gonzalez & Mehlhorn, 2016), and language processing (for reviews, see DeLong, Troyer, & Kutas, 2014; Huettig, 2015; Kuperberg & Jaeger, 2016).

Much of the recent research on predictive effects in cognition has focused on the visual domain. For example, Bar et al. (2006) present a model of vision in which object recognition is facilitated by a top-down prediction of the object identity based on low level visual information (see Murray et al., 2004 for a similar proposal). Evidence for this prediction comes from fMRI studies of the brain regions activated during object recognition; both temporal regions responsible for low level visual processing and regions in the pre-frontal cortex responsible for higher level processing were activated during object recognition. Crucially, Bar et al. demonstrate activity in the pre-frontal cortex 50ms before the activation of the regions associated with object recognition. This indicates that low level visual information was used to generate a prediction about likely objects, which in turn reduces the number of object representations that need to be considered and facilitates processing.

Prediction is also found in other, unrelated cognitive domains like social cognition. Frith and Frith (2006) review evidence for predictions about what other people are like and for predictions about the behavior of others. Observers, for instance, generate inferences about the intentions of actions and test these inferences by making predictions about how movement will continue. Additionally, Saxe et al. (2004) found increased activity in the brain region responsive to watching human movements, the posterior superior temporal sulcus (pSTS), when an actor paused behind a bookshelf as she walked from one side of a room to another. This finding suggests that participants predicted how long it should take the actor to emerge from behind the occluder and that they were surprised when that prediction was violated by the unexpected delay.

Recently, the field of psycholinguistics has turned its attention toward examining linguistic predictions during language comprehension. This dissertation continues in this tradition by evaluating the role of language experience on predictions made during language comprehension by introducing a novel population: children.

## 2.1 Linguistic prediction

Minimally, prediction in language comprehension can be defined as the effect of linguistic and non-linguistic context on the sentence processing mechanisms prior to bottom-up language input. This minimalistic version of prediction assumes that comprehenders build a representation of the context from the available information before receiving new bottom-up input. Thus, linguistic prediction could simply refer to the process of generating a representation of the context and the facilitatory effect this has on subsequent processing. There is evidence, however, that processing of input is not only facilitated, but predictively pre-activated. For example, in the domain of speech recognition it is widely recognized that bottom-up phonetic information pre-activates lexical information, which in turn predictively pre-activates upcoming phonemes (see Dahan & Magnuson, 2006 for a review). Throughout the dissertation, I will utilize this more specific description of prediction as involving predictive pre-activation of linguistic information at some level (or multiple levels) of representation.

Predictions at multiple levels of linguistic representation have been demonstrated during language comprehension. Comprehenders have been shown to use top-down information like the linguistic and non-linguistic context to predict upcoming parts of speech (Kimball, 1975), specific lexical items (DeLong et al., 2014; Federmeier & Kutas, 1999; Kamide, Altmann, & Haywood, 2003; Kutas & Hillyard, 1980a, 1980b, 1984; McDonald & Shillcock, 2003), semantic categories (Altmann & Kamide, 1999; Huettig & Janse, 2016; Lew-Williams & Fernald, 2007; Staub, Abbott, & Bogartz, 2012), fine-grained semantic properties (Altmann & Kamide, 2007; Borovsky, Elman, & Fernald, 2012; Knoeferle & Crocker, 2007), event structure (Chow, Smith, Lau, & Phillips, 2015; Kukona, Fang, Aicher, Chen, & Magnuson, 2011), and syntactic structure (Aoshima, Phillips, & Weinberg, 2004; Lau, Stroud, Plesch, & Phillips, 2006; Staub & Clifton, 2006; Stowe, 1986; Van Gompel & Liversedge, 2003).

Predictions at the lexical level were one of the first to be examined extensively by psycholinguists. Reading studies demonstrated that predictable words are read more rapidly than unpredictable words (Ehrlich & Rayner, 1981; Rayner & Well, 1996). Moreover, the N400 component of the ERP signal, a negative component that peaks approximately 400ms after the onset of the critical stimulus, has been shown to be sensitive to semantic processing and to reflect the predictability of words. Federmeier and Kutas (1999) collected ERP data on lexical prediction during constraining sentence contexts. Participants read contexts (e.g., *They wanted to make the hotel look more like a tropical resort. So along the driveway, they planted rows of…*) one word at a time. The final word of these contexts was either highly predictable given the context (*palms*), unexpected but from the same semantic category as the highly predictable one (*pines*), or unexpected and from a different category (*tulips*). The amplitude of the N400 was greatest for the unexpected word from a different semantic category (*tulips*) and smallest for the highly predictable word given the context (*palms*). Interestingly, the amplitude of the N400 to the unexpected word from the same semantic category was significantly smaller than that for the unpredictable word from a different semantic category (*pines* versus *tulips*). These results suggest that both the specific lexical item (i.e., *palms*) and the semantic category of that item were predicted given the sentential context.

Altmann and Kamide (2007) examined participants' ability to combine multiple sources of information to generate predictions about upcoming information. In two visual world eye tracking studies, they examined whether participants can combine semantic category and tense information from the verb to generate anticipatory fixations. Participants were presented with visual scenes including images that fit the semantics of the verb (e.g., *drink*); one of these images indicated that the action had already occurred (e.g., an empty wine glass), while the other indicated that the action had yet to occur (e.g., a full mug of beer). Fixations on these images were measured while participants comprehended past tense (*The man has drunk the beer*) and future tense (*The man will drink the beer*) utterances. In their previous work (1999), Altmann and Kamide demonstrated that comprehenders make anticipatory eye movements toward images in a scene when the verb provides sufficiently constraining semantic information (i.e., fixations on cake after the verb *eat* but not after the verb *move*). Thus, only fixations on a licit object of the verb (e.g., the beer, as an empty glass is not "drinkable") are expected if predictions are based solely on the semantics of the verb. During the auxiliary and verb, however, participants were more likely to fixate on the image that corresponded to the tense of the utterance than on the other image that fit the semantics of the verb or on a distractor image. In other words, they looked at the empty glass when the sentence was past tense and at the full mug was the sentence was future tense. Altmann and Kamide (2007) suggest that participants were able to integrate both the semantic category of the verb (which selects for a certain class of arguments, e.g., drinkable things) and tense information to generate anticipatory fixations on a likely object before that object was named.

This dissertation will focus on another level of representation: syntactic predictions. The investigation of syntactic predictions has received a fair amount of attention because they have important implications for how the parser generates syntactic structure and whether or not it makes syntactic commitments to reduce processing demands. Given my emphasis on syntactic predictions, this work is reviewed in the following section.

## 3 Syntactic predictions in processing

One of the major tasks of online sentence processing is to quickly and efficiently integrate incoming information into the partially built syntactic structure to generate an interpretation. In order to achieve this goal, the parser may predict the syntactic structure of upcoming input using the previous context or grammatical restrictions and pre-build syntactic structure based on this prediction. Sentence processing with syntactic prediction may be more efficient than processing without prediction because the parser can simply slot incoming information into the pre-built structure in a single step. If a verb phrase has been predicted, then the verb can be directly integrated into its structural position without first using processing resources to build the VP structure. Conversely, if a verb phrase has not been pre-built, the parser needs to first generate the VP structure before assigning the input (i.e., the verb) to the appropriate nodes, which can slow down processing.

It has been suggested that the resolution of argument structure ambiguities involves the incremental commitment to a particular syntactic structure (e.g., Ferreira & Patson, 2007; Linzen & Jaeger, 2015; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Thothathiri & Snedeker, 2008). This commitment occurs despite the fact that multiple continuations are compatible with the previous bottom-up input. For example, a visual world eye tracking study by Tanenhaus et al. (1995) presented an act-out instruction like *Put the apple on the towel in the box* to adults while they viewed a scene containing related images, e.g., an apple on a towel, a towel, a box, and a distractor item. At the point of processing the PP *on the towel* two interpretations are possible; this PP could either be the destination required by the argument structure of the verb *put* or a modifier of the NP *the apple*. The representations of the two compatible attachment sites are given in Figure 1.

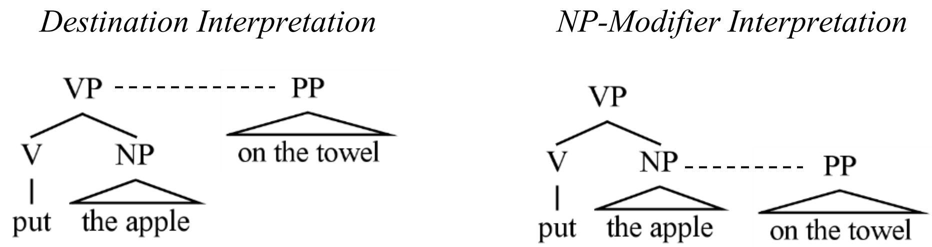


Figure 1. Representation of the competing structures involved in the PP-attachment ambiguity. On the left, the prepositional phrase *on the napkin* is attached to the verb phrase resulting in a destination interpretation (put it on the napkin). On the right, the PP is attached to the noun phrase resulting in an NP-modifier interpretation (the apple is on the napkin).

Tanenhaus and colleagues found that participants fixated on the empty towel while processing the first PP (*on the towel*), which suggests that they incrementally interpreted it as the destination of the verb. When the utterance continued with an additional PP (*in the box*), they shifted their fixations to the actual destination, the box.

In Tanenhaus et al.'s study and others like it, the incremental interpretation of the first PP as a destination is sometimes taken as evidence for prediction of the syntactic structure of the utterance. However, the definition of prediction adopted in this work crucially requires predictive *pre-activation* of representations before bottom-up information is available. These results do not fit the profile of predictive pre-activation because they involve the selection of a structure from the limited options provided by the bottom-up input, see Figure 1. The combination of the argument structure of *put*, which requires a destination, and the fact that a prepositional phrase can fulfill both a destination and NP-modifier role lead to the ambiguity. The argument structure of the verb is critical and must provide evidence for the ambiguity before facilitation can occur.

This is a case of predictive structural *selection* not predictive structure building. Thus, this dissertation focuses on the processing of long-distance dependencies, because gap predictions involve predictive structure building. In the remainder of the dissertation, I use 'syntactic prediction' to refer only to predictive structure building, not to predictive structure selection.

Predictive pre-activation of upcoming structure has been observed in a diverse group of syntactic contexts, and therefore syntactic prediction appears to be a robust phenomenon worthy of further study. Table 1 summarizes a selection of findings on the syntactic predictions involved in the processing of long-distance dependencies; the table additionally includes both the cue to prediction and the predicted structure. The first three rows divide up predictions during filler-gap dependency processing based on the predicted structure: direct object gaps (row 1), subject gaps (row 2), and parasitic gaps (row 3).

Staub and Clifton (2006) presented a case of predictive structure building in coordination contexts. The presence of *either* in sentential (1a) and NP (2a) coordination provides a strong cue for coordination, because *either* must be paired with a phrase headed by *or* for the sentence to be grammatical (i.e., **Either Linda bought the red car.*). Absent *either*, however, coordination is unpredictable, (1b) and (2b); there is no reason to predict coordination when it is not required for grammaticality. Because the (b) examples remain grammatical without the coordinated phrase (*Linda bought the red car* and *The team took the train to the game*), there is no reason to predict either sentential or NP coordination.

(1) a. *Either* Linda bought the red car or her husband leased the green one.
    b. Linda bought the red car or her husband leased the green one.

Table 1. Summary of studies demonstrating predictive structure building in the processing of long-distance dependencies.

| **Target structure** | **Method** | **Predicted structure** | **Cue to prediction** | **Citation(s)** |
|---|---|---|---|---|
| filler-gap dependencies | eye tracking; self-paced reading; ERP; fMRI | direct object gap (i.e., *active gap filling*) | filler | Many studies (see Section 3.2 for a review) |
| filler-gap dependencies | self-paced reading | subject gap | filler separated from subject by a modifying phrase; case-syncretized relative pronoun ; animate filler | Lee (2004); Levy et al. (2013); Wagers & Pendleton (2016) |
| filler-gap dependencies conducive to parasitic gaps | self-paced reading | parasitic gap | filler followed by a finite verb | Phillips (2006) |
| extraposed relative clauses | self-paced reading | NP modification (relative clause) | prenominal collocation with NP modification (*only those*) | Levy et al. (2012) |
| *either…or* coordination | self-paced reading | coordinated phrase headed by *or* with the same structure as the phrase *either* dominates | presence of *either* | Staub & Clifton (2006) |
| sluicing | self-paced reading | full hierarchical structure of the elided phrase | *wh*-phrase compatible with sluicing | Yoshida et al. (2013) |
| possessor NP ellipsis | ERP | NP ellipsis following a possessor | 2nd clause with similar possessor to 1st clause | Lau et al. (2006) |
| backward anaphora | eye tracking; self-paced reading | gender matched antecedent in the main clause subject position | cataphoric pronoun | Van Gompel & Liversedge (2003); Kazanina et al. (2007); Yoshida et al. (2014); Pablos et al. (2015) |

(2) a. The team took *either* the train or the subway to the game.
b. The team took the train or the subway to the game.

Staub and Clifton (2006) found that the processing of both sentential (1) and NP-coordination (2) was facilitated when the coordinated structure could be predicted in advance. In both cases, the coordinated structure headed by *or* was read more quickly when *either* was present. Also, while sentential coordination structures were sometimes misanalysed as NP-coordination when *either* was absent, no such misanalysis occurred when *either* was present. Taken together, these findings suggest that *either* predicts a conjunction headed by *or*, and given this prediction, the parser pre-builds the structure of the second conjunct assuming it is structurally identical to the first.

Several studies (Kazanina et al., 2007; Pablos et al., 2015; Van Gompel & Liversedge, 2003; Yoshida et al., 2014) have examined the predictions involved in the processing of another long-distance dependency, cataphora or backward anaphora. In this structure, a phrase containing an anaphora (i.e., a pronoun) precedes its antecedent. Because anaphora rely on their antecedents for an interpretation, the processing of a pronoun in a context without an antecedent could trigger a search for its antecedent. Van Gompel and Liversedge (2003) used eye tracking to demonstrate that when a cataphoric pronoun was processed, its antecedent was predicted online to be in the main clause subject position. To examine this, they used sentences in which the pronoun either matched (*he…the boy*) or mismatched (*she…the boy*) the gender of the subject noun phrase in the main clause, see (3).

(3) a. *Gender match:* When he was fed up, the boy visited the girl very often.
b. *Gender mismatch:* When she was fed up, the boy visited the girl very often.

Van Gompel and Liversedge found a *gender mismatch effect* on the first pass reading times at the main clause verb: first pass reading time was significantly larger when the gender of the main clause subject NP did not match the gender of the cataphoric pronoun. Pronouns and their antecedents must match in gender, so the gender mismatch effect indicated that the parser attempted to associate the cataphoric pronoun with the main clause subject, even though the subject was not the correct gender. Thus, a syntactic prediction about the position of the antecedent was cued by the presence of a cataphoric pronoun.

Another study by Lau et al. (2006) investigated syntactic prediction using Event-Related Potentials (ERP) responses to a grammatical category violation. Participants read sentences like (4) in which the second clause contained a grammatical category violation between a possessive NP and a following PP (e.g., the violation triggered by *Dana's of*). The first clause manipulated the expectation for a noun phrase following the possessor *Dana's* by altering the availability of ellipsis in the second clause.

(4) a. *Ellipsis possible:* *Although Erica kissed Mary's mother, she did not kiss Dana's *of* the bride.
    b. *Ellipsis impossible:* *Although the bridesmaid kissed Mary, she did not kiss Dana's *of* the bride.

In (4a), the form of the first clause direct object NP (*Mary's mother*) supports an ellipsis context, so no noun phrase following the second possessor (*Dana's*) is predicted. In (4b) on the other hand, the form of the first clause object NP (*Mary*) does not support ellipsis in the second clause (**Although the bridesmaid kissed Mary, she did not kiss Dana's*). In this condition, the lack of ellipsis availability means that a noun phrase is predicted to follow the possessor *Dana's*.

Lau et al. (2006) found an increase in left anterior negativity within 200-300ms of the onset of the ungrammatical continuation (*of the bride*) in both conditions. Critically, they found a greater increase in negativity in the non-ellipsis condition compared to the ellipsis condition. This attenuation in the effect of ungrammaticality is suggested to be the result of a syntactic prediction. In (4b), the possessor *Dana's* strongly predicts an NP category to complete the phrase grammatically. On the other hand, an ellipsis structure is predicted in (4a), so the category of the word following *Dana's* is less restricted (e.g., *…she did not kiss Dana's yesterday*, *…she did not kiss Dana's at the reception*, *…she did not kiss Dana's sister*). The greater negativity in (4b) reflects this highly constrained prediction, while the decreased negativity in (4a) reflects the prediction of an ellipsis structure.

Yoshida and colleagues (2013) examined a related ellipsis structure, sluicing, to test whether ellipsis structures are predicted during processing. As in Lau et al.'s (2006) study, participants read sentences that did not contain sluicing, but were in some cases temporarily compatible with a sluicing parse. For instance, the fronted *wh*-NP in (5a) (*which story*) is temporarily compatible with a sluicing structure, while the fronted *wh*-PP in (5b) (*with which story*) is not.

(5) a. *Sluicing possible:* Jane's grandfather / grandmother told some stories at the family reunion, but we couldn't remember which story about *himself* from the party his brother was so impressed with.
b. *Sluicing impossible:* Jane's grandfather / grandmother told some stories at the family reunion, but we couldn't remember with which story about *himself* from the party his brother was very impressed.

If a sluicing structure is predicted in (5a), then a gender mismatch effect should be observed at the reflexive, which indicates a mismatch between the gender of the reflexive and the gender of the subject of the sluiced structure (i.e., **which story about himself*

*[Jane's grandmother told]*). No such mismatch should be observed for sentences in which sluicing is impossible (5b). This is exactly what they found; participants read the reflexive more slowly only when the gender of the reflexive mismatched that of the subject of the sluice and the filler was a sluicing-compatible *wh*-NP. These results suggest that a sluicing structure is predicted when it is compatible with the structure of the input.

While the above reviewed studies provide compelling evidence for syntactic predictions, the main focus of this dissertation is on the syntactic predictions generated during filler-gap dependency processing. Thus, these predictions are discussed at length in the following section.

## 3.1 Syntactic predictions in filler-gap dependency processing

In a filler-gap dependency like (6), *what* (the filler) has been fronted from its underlying position as the complement of the verb (the gap).

(6) What did Sarah paint __?

In order to assign an interpretation to a filler, it must be associated with a gap, which can potentially be located in any upcoming structural position because filler-gap dependencies are potentially unbounded. For example, the gap position in (6) could have occurred later in the sentence as the complement of a preposition (7a), the complement of an embedded verb (7b), or the complement of an embedded preposition (7c).

(7) a. What did Sarah paint the fence with __?
b. What did Sarah say that John painted __?
c. What did Sarah say that John painted the fence with __?

Thus, the presence of a filler indicates the existence of a gap, but does not specify the gap's structural position.

Given the parser's goal of assigning an interpretation to the filler and the fact that the gap could occur in any number of structural positions, there are two possible procedures for identifying a gap: a gap-driven strategy and a filler-driven strategy (Fodor, 1978). In the gap-driven strategy, the parser waits until there is unambiguous evidence for the gap, i.e., a missing argument, before positing it. For example, the gap is utterance final in (6) and (7), so this bottom-up evidence is not provided until the utterance is completed (i.e., the utterance *what did Sarah paint…* does not continue). This strategy maximizes accuracy at the cost of delayed interpretation of the filler. Alternatively, because the presence of a filler indicates the presence of a gap, the parser may use the processing of a filler as a cue to actively predict a gap in the first available position (a filler-driven strategy). Only the filler-driven strategy allows for syntactic predictions during filler-gap dependency processing. A large body of work has shown that the parser uses this latter strategy, and, therefore, actively predicts the gap position (Crain & Fodor, 1985; Frazier & Clifton, 1989; Frazier & Flores D'Arcais, 1989).

## 3.2 Active completion of filler-gap dependencies

Previous research has established that, after processing a filler, adults predict a gap position before bottom-up information is available (*active gap filling*: Aoshima, Phillips, & Weinberg, 2004; Crain & Fodor, 1985; Fodor, 1978; Frazier, 1987; Frazier & Clifton, 1989; Frazier & Flores D'Arcais, 1989; Garnsey, Tanenhaus, & Chapman, 1989; McElree & Griffith, 1998; Omaki et al., 2015; Omaki & Schulz, 2011; Pickering & Traxler, 2003; Stowe, 1986; Traxler & Pickering, 1996; Wagers et al., 2015). For example, Stowe (1986) compared reading times at the direct object in sentences with a filler-gap dependency (8a) to those without such a dependency (8b).

(8) a. My brother wanted to know who Ruth will bring us home to __ at Christmas.
b. My brother wanted to know if Ruth will bring us home to Mom at Christmas.

The direct object, *us*, was read more slowly in the filler-gap dependency conditions (8a) than in (8b). Increased reading time on this region indicates surprise that the direct object position was filled with a pronominal NP. This *filled gap effect* indicates that a gap had been posited in the direct object position before confirming, via the information provided by a gap in the argument structure, that this position was unoccupied.

Additional evidence comes from the manipulation of the semantic fit of the filler and the verb so that the filler is either a plausible or an implausible object of the verb (Chow et al., 2015; Garnsey et al., 1989; Omaki & Schulz, 2011; Traxler & Pickering, 1996; Wagers & Phillips, 2014). Traxler and Pickering (1996) tracked participants' eye movements while they read sentences like (9).

(9) We like the book / city that the author *wrote* unceasingly and with great dedication about __ while waiting for a contract.

The critical verb, *wrote* in (9), is optionally transitive; while *book* is a plausible direct object of *wrote*, *city* is not. Traxler and Pickering found a *plausibility mismatch effect* in the first-pass reading time on the verb region (*wrote unceasingly*), i.e., first pass reading time was significantly larger in the implausible condition (*wrote the city*) compared to the plausible one (*wrote the book*). These results suggest that a gap was predicted in the direct object position, that this expectation was violated in the implausible condition, and that semantic fit between the verb and filler does not guide the dependency completion decision.

Converging evidence comes from Sussman and Sedivy (2003), who used a visual world design to investigate the syntactic predictions generated by a filler. Participants were presented a story – e.g., Jody was eating breakfast, saw a spider, and squashed it with her shoe – with an accompanying visual display of four related pictures (e.g., Jody, a spider, a shoe, and breakfast). Participants' eye movements to those pictures were tracked during a *wh*- or *yes-no* question (e.g., *What did Jody squash the spider with?* vs. *Did Jody squash the spider with her shoe?*) that followed the story. They found significantly more fixations on the object (*spider*) in the verb region for the *wh*-question condition compared to the *yes-no* question condition. They also found more fixations on the object than on the instrument (*shoe*) despite the fact that at the point of the verb there was no bottom-up evidence for a gap in the direct object position. Sussman and Sedivy concluded that the greater proportion of fixations on the object in the *wh*-condition were the result of an active search for a gap position triggered by the presence of a filler.

These results suggest that a directed object gap is posited at or by the verb, which is compatible with the view that gap positions are postulated predictively. Conversely, Pickering and Barry (1991) offer an alternative analysis that does not appeal to prediction. They suggest that the filler and its subcategorizer form a direct association when the subcategorizer is processed. According to this analysis, active gap filling reflects the association of the filler with the verb, not a syntactic prediction of the gap position. Crucially, the parser inspects the lexical and subcategorization information provided by the verb before the filler is associated. Therefore, completion of the dependency at the first verb should not be observed when the subcategorization of that verb does not allow a direct object, i.e., if it is intransitive.

Omaki et al. (2015) tested this hypothesis by comparing sentences with intransitive verbs (10c) to ones in which the intransitive verb is embedded within a relative clause island (10d). Islands are a grammatical constraint that prevents dependency formation (Chomsky, 1973, 1977; Ross, 1967), and the parser has been shown to respect them online (Stowe, 1986; Traxler & Pickering, 1996); a gap cannot grammatically be located within an island, so the parser does not attempt to actively fill the gap at the relative clause verb. The intransitive verb conditions were also compared with transitive verbs in the same conditions: non-islands (10a) and islands (10b).

(10) a./c. *Non-islands:* The costume party that the student planned / arrived eagerly for __ at the fraternity house was pretty lame.
b./d. *Islands:* The costume party that the student who planned / arrived eagerly attended / threw __ at the fraternity house was pretty lame.

If a direct object gap is predicted regardless of verb transitivity, there should be a *transitivity mismatch effect*, i.e., a reading time slowdown on the verb region when the transitivity of the verb does not support a direct object gap, in the non-island conditions. For first pass times, there was a significant interaction of transitivity and island status at the verb; first pass times on the intransitive verb were longer in the non-island conditions than in the island conditions. No such difference was observed for the transitive verbs. These findings suggest that a direct object was predicted before the verb was processed, and a processing slowdown occurred in the intransitive, non-island condition (10c) because the form of the verb was incompatible with this prediction. Omaki et al.'s results suggest that the parser generated expectations about the structure of the VP (i.e., its transitivity) before encountering the verb. Also, they suggest that active gap filling is predictive and that the prediction is occurring at least pre-verbally, if not at the point of processing the filler (see Aoshima et al., 2004 for another example of pre-verbal gap filling).

### 3.3 Syntactic predictions based on experience with language

The above evidence implies that the processing of filler-gap dependencies involves a syntactic prediction of the gap position sometime before the verb is processed. As discussed earlier, predictions are only beneficial if they are accurate. One way to maximize accuracy is to use the frequency of structures in the input to guide syntactic predictions. There are two forms of evidence that language experience does play a role in syntactic predictions: a) adult parsing biases reflect distributional biases in the input, and b) manipulation of language experience causes adaptation of these same parsing biases.

Probabilistic parsers provide an explicit account of the effect of language experience on syntactic predictions (Hale, 2001, 2003; Jurafsky, 1996; Levy, 2008; Linzen & Jaeger, 2015); syntactic structure is pre-built based on the most probable structural continuation. While there are several algorithms that implement probabilistic parsing, surprisal (Hale, 2001; Levy, 2008) has been particularly influential. With each new word, a probabilistic parser driven by surprisal uses statistical information to update hypotheses about the syntactic structure of the sentence and to make structural predictions about upcoming input. Suprisal measures the change in probability mass between the predicted and actual input. The surprisal of an input $w_i$ is the negative log probability of $w_i$ in its sentential context, i.e., the input thus denoted by $w_1 \ldots w_{i-1}$, see Equation (11) (Hale, 2001; Levy, 2008).

(11) $S_i = -\log P(w_i | w_1 \ldots w_{i-1})$

Surprisal is low when the probability of $w_i$ is high given the previous context; conversely, surprisal is high when the probability of $w_i$ is low. For example, in the sentence *in winter it is hot*, the word *hot* is infrequent given the previous context and has high surprisal. If *hot* were replaced with *cold*, however, it would have low surprisal because it is frequent considering the context. Put in terms of syntactic predictions, inputs that have high surprisal values disconfirm previous predictions and greatly influence future ones. An example of this is a verb that disambiguates a reduced relative rather than a main clause interpretation (i.e., *fell* in *The horse raced past the barn fell*). Reduced relatives are not frequent in the input, so they are not predicted. The processing of a second verb is unexpected given the predicted main clause interpretation of *raced*, so it has high surprisal and forces a reanalysis in favor of the reduced relative analysis. On the other hand, inputs with low surprisal values are compatible with existing syntactic predictions and increase the probability that the predicted structure is the correct one.

A surprisal-based probabilistic parsing account of active gap filling has not been explicitly proposed in the literature, though Pickering and Traxler (2003) suggest it as a possible account of their findings. Also, Hale (2006) and Levy (2008) both present corpus frequencies of the gaps in relative clauses, but this data is not directly related to active gap filling. Nonetheless, surprisal is a potential mechanism of active gap filling. Because syntactic predictions are based on probabilities, a probabilistic mechanism for active gap filling would suggest that direct object gaps, i.e., the actively predicted gap position, are predicted because they are the most probable gap position. Researchers often use distributional information derived from corpora to estimate the probabilities used in calculating surprisal (Demberg & Keller, 2008), but the distribution of gap positions in the input to adults has not yet been evaluated. I return to this issue in Chapter 2, and calculate the distribution of gap positions in the input to adults and children and in children's spontaneous utterances.

Sentence completion data from Pickering and Traxler (2003) can be used to estimate the frequency of gap positions as this data often reflects biases in the input distribution. This study suggests that direct object gaps are favored over other, post-verbal gaps (e.g., prepositional object gaps). Participants were asked to complete cleft sentences like *That's the cat that the dog worried*. Verbs used in the study are biased toward either direct object continuations with a noun phrase (NP-preference, e.g., *killed the man*) or prepositional phrase continuations (PP-preference, e.g., *worried about the man*). This subcategorization bias was assessed in a separate norming study. Additionally, the fillers were either plausible objects of the verb (*That's the cat that the dog worried…*) or implausible object of the verb (*That's the car that the dog worried…*). When the filler was a plausible direct object of the verb, participants preferred to complete the sentence with a gap in the direct object position, e.g., *That's the plane that the pilot landed __ at the airport*, regardless of the subcategorization preference of the verb (65% direct object gaps for plausible PP-preferences, 88% for plausible NP-preferences). Thus, participant's partial sentence completions favor direct object gaps over prepositional object gaps.

Assuming this completion data is representative of the input distribution, it can be used to infer what a surprisal model would predict for filler-gap dependency processing. When a filler has been processed and a subject gap has been ruled out, a surprisal-based probabilistic parser would predict a direct object gap because direct object gaps are the most probable continuation. The processing slowdown associated with the filled gap effect, the plausibility mismatch effect, and the transitivity mismatch effect (as discussed in Section 3.2) are also predicted by a probabilistic parser. This direct object gap expectation is violated by (respectively) an overt object NP, a semantic mismatch with the verb, and an incompatible argument structure. Because surprisal in all of these instances is high, processing is slowed. The fact that adults' gap predictions seem to reflect the distribution of gap positions in their input suggests that language experience does play a role in the generation of syntactic predictions.

Findings from structural adaptation studies provide evidence that suggests that language experience and syntactic prediction may have a causal relationship (Fine & Jaeger, 2013; Fine, Jaeger, Farmer, & Qian, 2013; Fine, Qian, Jaeger, & Jacobs, 2010; Jaeger & Snider, 2013, 2013; Linzen & Jaeger, 2015; Myslín & Levy, 2016). Fine et al. (2013) investigated how repeated exposure to improbable structures affected the comprehension of temporary syntactic ambiguities. Participants read sentences in which the verb form was temporarily ambiguous between a main clause and reduced relative interpretation, see (12).

(12) The experienced soldiers…
  a. *Main verb:* …<u>warned</u> about the dangers before the midnight raid.
  b. *Reduced relative:* …<u>warned</u> about the dangers conducted the midnight raid.

While the main clause / reduced relative ambiguity normally leads to a significant reading time slowdown on the disambiguating region in sentences with a reduced relative interpretation, *conducted* in (12b), participants exposed to reduced relative clauses demonstrated reduced processing difficulty on this region. Furthermore, these participants began displaying processing difficulty on the disambiguating region in sentences with a main verb interpretation, *before* in (12a). Fine et al. suggest that these finding indicate adaptation of the sentence processing mechanisms to the distribution of syntactic structures in the input. Exposure to the reduced relative continuation updated the probability of encountering that structure, which in turn lead to increased expectation for that structure and decreased processing difficulty. Thus, experience with reduced relatives had a direct effect on processing behavior.

Furthermore, Fine and colleagues argue in this work and others (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013) that syntactic adaptation is a form of implicit learning. In particular, they compare the ability to tailor sentence processing behaviors to recent language experience to children's and adults' ability to use statistical regularities to extract information from a stream of speech in an artificial language (e.g., Gómez & Gerken, 1999; Saffran, Aslin, & Newport, 1996; see Romberg & Saffran, 2010 for a review). In fact, they suggest that the learning process associated with adaptation is the same, or at least very similar, to the one active during language acquisition. In other words, there may be a continuous statistical learning mechanism that is active throughout life.

This connection between statistical learning in infancy and adaptation in adulthood in turn suggests the potential for a tight relationship between learning the distribution of syntactic structures and learning to predict those structures. This link, however, is not particularly justified by the currently available developmental data. For example, it is not known if children parsing biases are reflective of their input distribution. Moreover, adaptation studies have not been attempted with children. Given the similar learning process assumed by this statistical learning account, like adults, children should be sensitive to changes to the distribution in their recent language experience. Both of these open questions are addressed in this dissertation. Chapter 2 examines children's syntactic predictions and compares them to the distribution of syntactic structures in their input and their productions. Chapter 4 investigates whether or not children can adapt their syntactic predictions on the basis of recent input.

The generalizability of adaptation effects is an additional concern. Such effects have generally been demonstrated in the lab within a single experimental session. It is unclear if these same effects would be found "in the wild." Chapter 3 further investigates adaptation effects in structures generating predictive structure building processes (i.e., filler-gap dependencies) as compared to those generating predictive structure selection processes (e.g., main clause / reduced relative ambiguity resolution) utilized by Fine et al. (2013). It also examines whether adaptation effects are found when the exposure period is not within the same experimental setting as the test phase.

## 4 Developmental data as a window into adult sentence processing

Evidence from adult filler-gap dependency processing suggests that there is a relationship between language experience and syntactic predictions. As discussed earlier, implementations of probabilistic parsers use distributional information to approximate the likelihood of particular structures. Because these probabilities are derived from the input, language experience should play a crucial role in syntactic prediction. Children, then, are an ideal population for attesting the role of experience in syntactic predictions because they are still learning the structural distribution. According to the probabilistic account, children's predictions should be adult-like if they have been exposed to an adult-like distribution of syntactic structures. Thus, the relationship between children's predictive behaviors and their language experience has the potential to reveal how critical statistical information is for prediction. Also, if children are making immature predictions and their input distribution is non-adult-like, probabilistic models provide a potential avenue for development: children's predictions should become adult-like when they have acquired the adult distribution of structures.

## 4.1 Does the developing parser make syntactic predictions?

A growing body of evidence suggests that children are capable of adult-like incremental comprehension by the age of two (Lew-Williams & Fernald, 2007; Mani & Huettig, 2012; Borovsky et al., 2012; Nation, Marshall, & Altmann, 2003), but these demonstrations have been limited to dependencies with local relations (e.g., the semantic fit between a verb and its direct object). One type of evidence for children's incremental comprehension comes from studies that investigated predictions of upcoming nouns. A large body of work on adults has shown that they use semantic information provided by the verb and other contextual information to predict upcoming arguments, e.g., *the boy will eat* predicts an edible direct object (Altmann & Kamide, 1999, 2007; Kamide et al., 2003; Staub et al., 2012). In particular, several visual world studies have found that adults fixate on an image of a semantically plausible object while still processing the verb (e.g., fixating on a picture of a cake while processing the verb *eat*). These early fixations indicate that participants are anticipating the upcoming direct object while processing the verb.

Children as young as 2-years-old with high vocabularies demonstrate the same pattern of anticipatory fixations as adults (Borovsky et al., 2012; Mani & Huettig, 2012; Nation et al., 2003). In fact, children between 3- and 10-years-old make anticipatory fixations on a compatible direct object even when non-linguistic contextual information must be considered in addition to the semantics of the verb (Borovsky et al., 2012). Children were shown a display that included pictures of two objects associated with one verb (e.g., *hide*: a bone and treasure) and two objects associated with an alternative verb (e.g., *chase*: a cat and pirate ship). In order to identify the bone as the object in a sentence like *The dog hides the bone* the contextual information from the subject, i.e., *the dog*, must be combined with the selectional information from the verb, i.e., *hides*. Both adults and high vocabulary children made anticipatory fixations on the correct object (i.e., the treasure) during the verb region.

While these anticipatory fixations could be interpreted as a syntactic prediction of the direct object (and thus, the direct object position), alternate explanations appealing to thematic priming are also compatible. Kukona and colleagues (2011) demonstrated that adults fixate on verb-related agents in addition to verb-related patients during the verb, even when the agent role has already been filled by another entity. Given the sentence *Toby arrests the crook*, participants fixated on both the crook (a compatible patient) and the policeman (a compatible agent) while processing the verb *arrest*, despite the fact that the actual agent, *Toby*, had already been processed and was pictured. These results suggest that anticipatory fixations during the verb may be the result of verb-based thematic priming rather than of a syntactic prediction for the direct object position.

Children's resolution of attachment ambiguities has also been taken as evidence for their incremental comprehension (Choi & Trueswell, 2010; Kidd, Stewart, & Serratrice, 2011; Snedeker & Trueswell, 2004; Trueswell, Sekerina, Hill, & Logrip, 1999). For instance, Snedeker and Trueswell (2004) examined 5-year-olds' processing of PP-attachment ambiguities, as in (13).

(13) a. Choose the cow with the stick. (Modifier Bias)
b. Feel the frog with the feather. (Equi Bias)
c. Tickle the pig with the fan. (Instrument Bias)

In (13c), the prepositional phrase (e.g., *with the fan*) can either modify the verb (instrument interpretation, e.g., use the fan to tickle the pig) or the noun phrase (modifier interpretation, e.g., the pig holding the fan). While processing these ambiguous sentences, Snedeker and Trueswell tracked participants' eye movements to a display of toys. Crucially, the subcategorization bias of the verb in the ambiguous utterance was manipulated such that it biased the interpretation toward the NP modifier interpretation (13a), the verb modifier interpretation (13c) or was not biased toward either of the attachment options (13b). If children can make use of these biases, then their interpretations should reflect these biases; if, on the other hand, children are not able to use the verb biases, a consistent pattern of interpretations across all conditions is expected. Five-year-olds' proportion of fixations on the instrument toy was greatest for the instrument biased verbs and least for the modifier biased verbs. This effect emerged early in the ambiguous phrase, which indicates that children were using the lexical cues provided by the verb to incrementally assign an interpretation to the ambiguous input.

The case of the PP-attachment ambiguity suggests that children can integrate lexical information in their structure selection processes during real time sentence comprehension. However, the process of resolving this ambiguity does not involve syntactic prediction. Rather, it involves the facilitated selection of a structure from two alternatives that are available once the bottom-up information has been processed. Syntactic predictions, on the other hand, involve the projection of structure before bottom-up evidence in favor of that structure has been processed. Thus, another structure is needed to investigate the development of syntactic predictions. As children have acquired the syntax of filler-gap dependencies by 20-months-old (Gagliardi, Mease, &

Lidz, 2016; Seidl, Hollich, & Jusczyk, 2003), they are a candidate structure for examining children's syntactic predictions.

Though active gap filling is a significant source of evidence for syntactic predictions in the adult sentence processing literature, few studies have examined whether children generate syntactic predictions during filler-gap dependency processing (Lassotta, Omaki, & Franck, 2015; Love, 2007; Omaki, White, Goro, Lidz, & Phillips, 2014), and none have provided a fine time course measure. Love (2007) conducted a study using the cross-modal picture priming paradigm. It was found that, at the offset of the verb, children performed a classification task more quickly when the picture to be classified was of the filler compared to another noun named in the stimulus or an unnamed noun. These results were taken to indicate that the filler was reactivated at the verb in anticipation of integrating it, and thus pre-activated for the classification task. Because the task occurred at the end of the verb, however, it is not clear that this must be a predictive effect and other factors (e.g., local coherence with the verb) may be responsible for these results.

The two other previous studies used children's interpretations of ambiguous bi-clausal questions, e.g., *Where did Lizzie tell someone that she was gonna catch a butterfly?*, to examine the development of filler-gap dependency processing in French, English, and Japanese (French: Lassotta et al., 2015; English & Japanese: Omaki et al., 2014). There are two possible interpretations of these questions: *where* refers to either the location of the event in the main clause (e.g., the telling event) or the location of the event in the embedded clause (e.g., the catching event). Across all three languages, both adults and 5-year-olds prefer to associate the *wh*-phrase with the linearly first clause, which is the main clause in English and French (i.e., the telling event) but the embedded clause in Japanese (i.e., the catching event). According to the authors, this preference was the result of active gap filling; the filler was interpreted at the first verb, rather than at the matrix verb ignoring word order differences, because children and adults were actively associating the filler with a plausible gap position. Thus, 5-year-old's adult-like preferences suggest that children can and do actively associate the gap with the first available verb.

Though these findings present converging evidence for children's ability to actively fill the gap, they did not utilize online methodologies that would allow an evaluation of children's predictions during real time comprehension. Because syntactic predictions unfold as the sentence is processed, this real time evaluation is critical for determining whether adult-like syntactic predictions are being generated. Chapter 2 addresses this issue by examining children's active gap filling behavior in the visual world.

## 5 Outline of the dissertation

The remainder of the dissertation is organized as follows. Chapter 2 addresses the question of whether children can generate syntactic predictions during the processing of filler-gap dependencies. While previous studies have examined this issue (Lassotta et al., 2015; Love, 2007; Omaki et al., 2014), they utilized offline methodologies. Chapter 2 attempts to fill this gap in the literature with a visual world eye tracking study of active gap filling in 5- to 7-year-olds and finds that children of all ages do not fixate on the target object during the verb region of *wh*-questions (e.g., *Can you tell me what Emily was eating the cake with __?*). This suggests that children are not making an adult-like direct object gap prediction in this region. In the object NP region of *wh*-questions, both adults and children fixate on the target instrument (i.e., the answer to the question). This indicates that both age groups are predicting a prepositional object gap after a direct object gap is ruled out by the presence of an overt object NP. The probabilistic parsing account of prediction is evaluated in light of these results and a distributional analysis of gap positions in adult's and children's input.

In Chapter 3, I adapt the syntactic adaptation paradigm of Fine et al. (2013) to filler-gap dependency processing to examine the effect of local language experience on adult's predictive processing. If predictions are driven by the distribution of syntactic structures in the input, it should be possible to mediate adult's syntactic predictions by manipulating the structures in their local language experience. Specifically, I present two blocked syntactic adaptation experiments using eye tracking during reading methodologies. In these studies, participants are exposed to a block of input skewed toward post-verbal gap positions other than direct object gaps (i.e., prepositional object gaps). I find that this skewed input leads to diminished direct object gap predictions, but no related increase in prepositional object gap predictions. A follow-up study presents the exposure block as an independent experiment to test the generalizability of the adaptation effect. In this study, active gap filling at the verb did not decrease. Taken together, these results suggest that adult's syntactic predictions can be modulated by their recent experience with syntactic structures, but that these effects may be limited to quite specific contexts (e.g., within a single experiment).

Chapter 4 explores whether it is possible to trigger children's active gap filling by priming the direct object gap structure. First, I present a comprehension priming study using a novel picture completion task. A confederate experimenter produced either direct object gap (*What was the girl drawing __ with the crayon?*) or prepositional object gap (*What was the girl drawing the cat with __?*) *wh*-question primes, which the 5-year-olds comprehended and answered. Following the priming phase, they participated in the visual world eye tracking study from Chapter 2. Five-year-olds duplicated their non-adult-like processing of *wh*-questions (as in Chapter 2) no matter which structure children comprehended. In other words, comprehension priming did not prime active gap filling. Following the results from Chapter 3 and findings that production and prediction are tightly linked (Mani & Huettig, 2012; Pickering & Garrod, 2007, 2013), Chapter 4 also presents a production priming version of the picture completion + visual world eye tracking study. Rather than comprehending direct object and prepositional object gap questions, children were primed to ask these questions of the confederate experimenter. Surprisingly, active prediction of a direct object gap at the verb increased for the group that produced *prepositional object gaps*. I suggest that the difficulty inherent in producing this structure, as demonstrated by its rarity in children's productions and by children's significant difficulty in producing it, strengthened children's abstract representation of filler-gap dependencies. This strengthening, in turn, led to increased prediction of direct object gaps. Together, these results suggest that priming may be a learning mechanism for syntactic prediction, but only when the production system is activated.

Finally, Chapter 5 reviews the overall findings in this dissertation on the role of language experience on the syntactic predictions generated by the mature and developing parser. I argue that the only representation of a gap prediction compatible with these findings is a non-specific prediction of an upcoming gap rather than a specific structural prediction, and propose an alternative representation that can account for the findings presented in this dissertation. I also discuss the future directions and open questions on probability driven syntactic predictions and the development of these predictions.

# CHAPTER 2 – THE DEVELOPMENT OF ACTIVE GAP FILLING

## 1 Introduction

The adult filler-gap dependency processing literature indicates that there is a relationship between language experience and syntactic predictions. In fact, probabilistic parsers critically rely on language experience, in the form of distributional information, to approximate the likelihood of particular structures and to guide parsing decisions. While adults likely have a well-established baseline distribution of structural frequency, children are in the process of acquiring this distributional information. Because children are in the midst of this acquisition process, they may be particularly susceptible to changes to the distribution of structures in their recent experience. Thus, they are a valuable population for testing the predictions of a probabilistic parser.

In this case, children's processing of filler-gap dependencies can provide evidence either for or against a probabilistic parsing account of active gap filling. There are two factors that are crucial for this evidence: whether or not children actively fill the gap and whether or not they are exposed to an adult-like distribution of gap positions. If children's active gap filling behavior mimics the input distribution, this would provide evidence for a probabilistic account of active gap filling. In other words, either children actively fill the gap and have an adult-like distribution of gap positions in their input or they do not actively fill the gap but have a non-adult-like distribution, such as a uniform distribution or a distribution skewed away from direct object gaps. On the other hand, if there is a mismatch between active gap filling behavior and statistical information, this would constitute evidence against the probabilistic parsing account of active gap filling. This chapter explores both of these factors. The first experiment is a visual world eye tracking study of children's online processing of filler-gap dependencies, while Experiment 2 explores the distribution of gap positions in the input for both children (i.e., child directed speech) and adults as well as children's own productions.

## 1.1 Acquisition of filler-gap dependencies

Before examining children's online processing of filler-gap dependencies, it is important to establish that they have acquired the structure of *wh*-questions. Knowledge of this structure, especially that the *wh*-element is fronted from an underlying position, is a prerequisite for actively constructing the dependency. In order to make a gap prediction, a comprehender must 1) be able to identify a filler, 2) know that the filler must be associated with an upcoming gap position, and 3) be able to categorize the filler in order to identify potential gap positions. All three of these properties are also required for acquisition of the structure of filler-gap dependencies. Thus, children that have acquired this structure should be capable of generating gap predictions.

Studies that investigated children's production of *wh*-questions (Stromswold, 1995; Thornton, 1995; see also de Villiers, Roeper, & Vainikka, 1990) demonstrated that the requisite knowledge to produce a *wh*-question is available as early as 20 months (1;8). Thornton (1995) elicited questions with referential (i.e., D-linked) and non-referential (i.e., bare) *wh*-phrases and consequently examined older children ranging from 4;1 to 5;4. Stromswold (1995), on the other hand, was interested in the age of first production of *wh*-questions and examined the productions of children as young as 14 months old (1;2). She found that some children produced their first *wh*-questions as early as 20 months (1;8), with 28 months (2;4) as the average age of first production.

Relying on production data, however, could result in a conservative estimate of the age of acquisition of *wh*-questions. Generally, comprehension of a form precedes production of that form during acquisition (Clark, 1993 among many others). While there are many previous studies on the comprehension of *wh*-questions and relative clauses (Belletti, Friedmann, Brunato, & Rizzi, 2012; de Villiers & Roeper, 1995; Friedmann, Belletti, & Rizzi, 2009; Gagliardi et al., 2016; Goodluck, 2010; Seidl et al., 2003; Tyack & Ingram, 1977), they often focus on children much older than 20 months.

Preferential looking studies on infants' comprehension of *wh*-questions, however, have found converging evidence that 20-month-olds are able to reliably assign adult-like interpretations to both subject and object *wh*-questions (Gagliardi et al., 2016; Seidl et al., 2003). Gagliardi and colleagues (2016) showed 20-month-olds videos of two dogs and a cat; the first dog bumped the cat, then the cat bumped the other dog. Following this exposure, infants were shown each dog on either side of the screen, and their fixations on these dogs were measured following either a subject gap (1a) or direct object gap (1b) question.

(1) a. *Subject gap:* Which dog __ bumped the cat?
b. *Direct object gap:* Which dog did the cat bump __?

Twenty-month-olds looked more toward the agentive dog (i.e., the dog that bumped the cat) after a subject gap question and more toward the other, non-agentive dog (i.e., the dog that was bumped) after a direct object gap question. Thus, infants were looking at the correct dog given the structure of the question, which suggests that 20-month-olds were associating the filler with the gap in the argument structure and that they have acquired the structure of filler-gap dependencies.

Furthermore, there is evidence that 3-year-olds do not extract *wh*-words from islands (de Villiers & Roeper, 1995), which suggests that children have sophisticated knowledge of the syntax of *wh*-dependencies relatively early. De Villiers and Roeper (1995) asked 3- to 5-year-olds questions including subject and object relative clauses (e.g., *How did the man rescue the cat __ that broke her leg?*) that allow for mistaken interpretation if extraction of the *wh*-word from the relative clause is permitted in the child's grammar. In this example, the child could give the grammatical answer, i.e., how the cat was rescued, or the ungrammatical answer that indicates extraction from the relative clause, i.e., how the cat broke her leg. Children rarely gave the latter answer, which de Villiers and Roeper take as evidence that relative clauses act as barriers to *wh*-movement early in acquisition. Because the age range of interest, 5;0 to 8;0, is significantly above the 20-month threshold, I assume that the participants in this study have acquired the structure of *wh*-questions.

## 1.2 Previous developmental studies of active gap filling

Although active gap filling has been robustly demonstrated in adults, only three studies to date have investigated whether or not the child parser actively completes filler-gap dependencies. This section reviews two previous studies: Love (2007) and Omaki et al. (2014; see also Lassotta et al., 2015). The third is Experiment 1, my own visual world study, which investigates 5- to 7-year-olds' real time processing of *wh*-questions.

In a cross-modal picture priming study, Love (2007) investigated whether 4- to 6-year-olds reactivated the filler noun phrase at the verb. Participants heard sentences like *The zebra that the hippo had kissed __ on the nose ran away*, and made an edibility judgment (able to be eaten vs. not able to be eaten) to a picture presented at the offset of the verb. Participants responded more quickly when the presented picture was of the fronted direct object NP, e.g., *zebra*, than when it was of an unrelated animal, e.g., *camel*, or of the relative clause subject NP, e.g., *hippo* (for a related study, see Roberts, Marinis, Felser, & Clahsen, 2007). Conversely, no difference in reaction time was observed when the pictures were presented at the offset of the subject of the relative clause. Love concluded that 4- to 6-year-olds, like adults, reactivated the fronted direct object noun phrase at the verb in anticipation of a direct object gap.

It is not clear, however, that this facilitation must indicate that the filler is being actively interpreted and integrated as the object of the verb. An alternative explanation does not require reactivation of the filler to derive these effects. Because the picture is presented at the end of the verb, children may be interpreting the picture as the direct object of the local sentence fragment (e.g., *the hippo had kissed…*). Integrating *zebra* as a new object produces a syntactically and semantically locally congruent sentence (*the hippo had kissed the zebra*), while integrating *hippo* as an object is less natural (*the hippo had kissed the hippo*). Also, this congruent sentence is potentially easier to process than *the hippo had kissed the camel* because *zebra* had been mentioned in the previous context.

Omaki et al. (2014) investigated 5-year-old's interpretation of ambiguous bi-clausal *wh*-questions in English, see (2), and Japanese.

(2) Where did Lizzie tell someone [that she was gonna catch butterflies]?

In both languages, it is grammatical for a *wh*-filler to be associated with a gap in either the matrix or embedded clause. In English, the matrix verb is processed before the embedded verb; however, because Japanese is a head-final language, the embedded clause verb precedes the matrix clause. Both children's and adults' preferred interpretations of questions like (2) were driven by the order of the clauses. Speakers of both languages prefer to associate *where* with the first available verb, which is the main clause verb in English but the embedded clause verb in Japanese. This preference is interpreted as the result of active gap filling; the decision to interpret the filler at the first verb, rather than at the matrix clause regardless of word order, arises from an active association of the filler with a plausible gap position. Thus, 5-year-old's adult-like preferences suggest that children are also actively associating the filler with the first available verb.

Further studies examined French and Japanese learning children's answers to questions that rendered a gap in the first clause impossible because an overt PP occupies the position of a potential gap, e.g., (translated from French) *Where did Aline explain in the living room that she was going to catch butterflies?* (French: Lassotta et al., 2015; Japanese: Omaki et al., 2014). Despite the presence of the locative prepositional phrase in the first clause, both French and Japanese children continued to associate *where* with that clause. Omaki et al. suggested that this interpretation is the result of a failed reanalysis; children were unable to reanalyze their initial, active interpretation of the gap in the first clause when that gap position was filled. While suggestive that children are capable of active gap filling, these studies lacked time course evidence, so it is unclear when children settle on the first clause interpretation. Also, Omaki et al. examined two potential gap positions across clauses (main vs. embedded) rather than within a clause (direct object vs. prepositional object) as is common in adult research on active gap filling. It is possible that children process filler-gap dependencies differently based on whether potential gap positions are intra-clausal versus cross clausal.

Despite this complementary evidence for children's active gap filling, neither Love (2007) nor Omaki et al. (2014) provide strong evidence for active gap filling during *online* processing. The syntactic gap prediction associated with filler-gap dependency processing critically unfolds incrementally during real time comprehension. The offline results from Love and Omaki et al. suggest that children are generating direct object gap predictions incrementally, but do not provide direct evidence for this. Thus, investigating children's processing of filler-gap dependencies using real time eye tracking measures is the focus of this first chapter. Visual world eye tracking allows us to observe intermediate interpretative processes as the sentence unfolds, and consequently, to determine whether or not children are predicting gap positions in an adult-like manner.

## 2 Experiment 1 – Visual world eye tracking

The current study examines whether children between the ages of 5- and 7-years-old generate gap predictions during filler-gap dependency processing. This age range was chosen for several reasons. First, many studies on children's processing utilize 5-year-old participants (e.g., Choi & Trueswell, 2010; Kidd et al., 2011; Trueswell et al., 1999) including the previous studies on child filler-gap dependency processing (Lassotta et al., 2015; Love, 2007; Omaki et al., 2014), and anecdotal evidence from Trueswell et al. (1999) suggests that 8-year-olds are adult-like in their ability to recover from garden path sentences. This indicates that 5- through 7-years-old is a useful age range for examining the development of active gap filling. Additionally, 5-year-olds are able to sit through the task without getting overly restless.

In addition to age, children's active gap filling behavior may be mediated by other factors such as vocabulary size. Studies examining children's incremental processing at the verb suggest that there is a robust relationship between vocabulary size and processing speed (Borovsky et al., 2012; Mani & Huettig, 2012; Nation et al., 2003). Mani and Huettig (2012) found that production vocabulary size was significantly correlated with 2-year-old's ability to anticipate a semantically related direct object while processing a verb (e.g., anticipating *cake* when the verb is *eat*). Similarly, two studies with older children (3- to 10-year-olds: Borovsky et al., 2012; 10- and 11-year-olds: Nation et al., 2003) found that comprehension vocabulary size was significantly correlated with the speed of anticipatory fixations on a semantically appropriate direct object. Also, children with large comprehension vocabularies were making these anticipatory fixations at the same speed as adults. Given these findings, it is reasonable to expect that individuals' vocabulary size may play a role in children's predictive ability in the current experiment. To test this hypothesis, a measure of children's receptive vocabulary size was administered following the main visual world eye tracking experiment.

In order to examine the development of gap predictions during filler-gap dependency processing, children comprehended temporarily ambiguous *wh*-questions like (3), which provide two opportunities for active gap filling.

(3) Can you tell me what Emily was eating the cake with __?

As in other studies of filler-gap dependency processing, the first opportunity is in the verb region; active association of the filler with the verb would indicate a direct object gap prediction. Upon hearing the direct object, however, this interpretation can be ruled out and an alternate gap position must be located. In these questions, the next plausible gap position is the complement of a preposition. Thus, active association of the filler with the preposition indicates a prepositional object prediction. The inclusion of two regions of interest allows us to examine whether children can generate gap predictions generally and direct object gap predictions specifically.

## 2.1 Method

### 2.1.1 Participants

Fifty-six English-speaking children between the ages of 5;0 and 8;0 (mean age = 6;4, 29 females) participated in the study.[1] These children were recruited from the communities surrounding Johns Hopkins University and the greater Baltimore area. Six additional children participated in this study, but their data was excluded from analyses due to technical difficulty ($n$ = 1), lack of attention ($n$ = 2), or because they participated in a previous version of the experiment ($n$ = 3).

In addition, 24 adult native speakers were recruited from the Johns Hopkins University community and were paid for participating in this experiment. One additional adult participant was tested but their data was excluded from analyses due to technical problems ($n$ = 1).

### 2.1.2 Materials

The stories and questions used in this experiment were derived from those used in Omaki (2010) with minor changes. The stories in Omaki (2010) crucially involved two events, which introduced uncertainty about the content of the question before the verb was heard.

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[1] The group of children consisted of 20 5-year-olds (mean age = 5;5, age range = 5;0-5;11, 9 females), 20 6-year-olds (mean age = 6;5, age range = 6;0-6;11, 12 females), and 16 7-year-olds (mean age = 7;5, age range = 7;0-8;0, 7 females).

This ensured that fixation patterns represent online processing of the filler-gap dependency rather than prediction about a salient event.

*Story and display design.* Ten target and ten filler stories consisting of clipart animation were constructed. These stories were followed by either a *wh*- or *yes-no* question about one of the events (see below for details of the question design). Each story followed the same basic structure: the character on the display introduced him or herself, the two events were mentioned, the character chose one and completed it, and the character completed the remaining event. A sample target story with a target question is provided in (4).

(4) Hi, my name is Emily. Today I'd like to eat some cake, but I also need to wash the dishes. Hmm, what should I do first? I think I'm gonna eat the cake, and for that I need a fork. Mmm! That cake was yummy. Now it's time to wash the dishes. I'm gonna need to use a sponge. Oh, those dishes are so clean. I did a great job today.

Question: Can you tell me what Emily was eating the cake with __?

Given that each story involved a subject and two distinct events with associated objects and instruments, each display consisted of five pictures (see Figure 2): 1) the subject (e.g., Emily), 2) the object from the first task (e.g., cake), 3) the instrument from the first task (e.g., fork), 4) the object from the second task (e.g., dishes), and 5) the instrument from the second task (e.g., sponge). The position of each type of picture was balanced across stories such that they appeared in all five locations (e.g., the subject did not always appear in the bottom left position). In order to make the display more engaging, animations were added to accompany each event. For example, when the task was eating cake with a fork, the fork picture moved to the cake picture. Most of these animations left a "trace" of the event so that there was a visual representation of the events in the story. In the case of eating cake, a slice of cake was replaced by crumbs and the fork became dirty. These event traces were intended to facilitate relevant eye movements by increasing the available visual information about the completed events. Figure 2 shows the beginning (i.e., before either event) and end of the display associated with (4). The list of target story scripts and questions used in this experiment are provided in Appendix A.

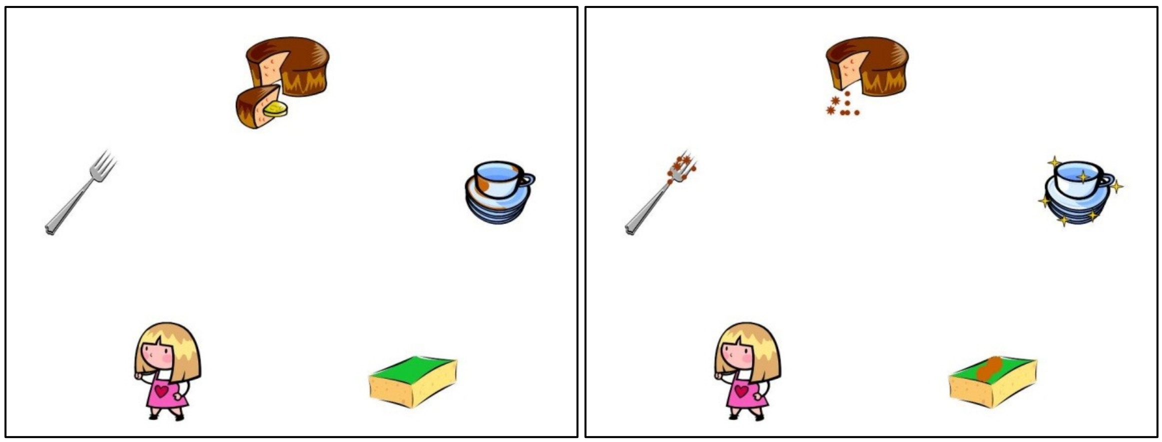

Figure 2. A sample story display. The initial phase is on the left, and the final phase is on the right.

*Questions.* Questions in this experiment were of two types: *wh*-questions and *yes-no* questions. Because we are interested in filler-gap dependency processing, the *wh*-questions are the critical condition. The *yes-no* target questions serve as controls for the time course and proportion of fixations on the pictures in the absence of a filler-gap dependency. In order to maximize the structural similarity across conditions, all questions were embedded. This ensures that the only difference between the questions is the presence or absence of a filler-gap dependency as indicated by *what* or *if*. An example of each type of question is presented in (5).

(5) Can you tell me…
    a. what Emily was eating the cake with __ ? (*wh*-question)
    b. if Emily was eating the cake with the fork? (*yes-no* question)

All questions used the progressive form of the verb (*was V-ing*) to increase verb duration, so that there would be a sufficient number of frames in which to observe eye movements. The average duration of the target verbs was 664ms (minimum = 475ms, maximum = 947ms).

For each of the ten target stories, both a *wh-* and *yes-no* question were constructed for each event. This resulted in 40 total target questions (4 per story, 2 *wh-* and 2 *yes-no* questions). In the *wh*-questions, the *wh*-phrase *what* was extracted from an instrument prepositional phrase (PP) headed by the preposition *with*. The *yes-no* questions also included an instrument PP. The answer to target *yes-no* questions was always "yes."

A single question was constructed for each filler story. The 5 filler *wh*-questions asked about the direct object rather than the instrument (e.g., *Can you tell me what Esmeralda was squashing __ with the magic wand?*). The 5 filler *yes-no* questions had the same structure as the targets, but the correct answer to these questions was "no." This was done by substituting either the object or instrument from the non-questioned event for the correct object or instrument (e.g., *Can you tell me if Ethan was painting the TV with the brush?* in which Ethan actually painted the door).

Four lists were generated by counterbalancing the target questions such that each participant only heard one version per story. Each list consisted of 5 *wh*-targets and 5 *yes-no* targets. Half of these questions asked about the first event in the story, while the other half asked about the second event. The 10 targets were combined with the 10 fillers for a total of 20 story-question combinations.

*Audio recording.* The narratives were recorded by a female native speaker of American English. An additional female native speaker of American English recorded the questions. The narratives and questions were read with child-directed prosody and were recorded with a sampling rate of 44.1 kHz. The sound files and animations were incorporated into a single movie file for presentation.

### 2.1.3 Procedure

The 20 total trials were grouped into four sets of five trials. All trials began with a narrative and associated movie display. Following the story, a fixation cross appeared in the center of the screen and remained until the participant fixated on it for 1000ms. This fixation triggered the reappearance of the last display from the story. The display was accompanied by audio of a question about one of the events in the story, and participants were prompted to answer this question aloud.

Participants were seated with their eyes approximately 24 inches in front of an EyeLink 1000 remote eye-tracker (SR Research, Toronto, Ontario, Canada), which is integrated in an LCD arm mount with a 17-inch computer monitor. The eye-tracker had a sampling rate of 500 Hz and a spatial resolution of less than one degree of visual angle. The audio was presented through free-standing speakers on both sides of the monitor. Participants were instructed to look at the pictures during the story and the question. Head movements were unrestricted, but participants were asked to minimize their movements and to look at the pictures by only moving their eyes. A 5-point calibration was performed before beginning the experiment. The entire procedure including consent, instructions, calibration, the experiment, and debriefing took approximately 25 to 30 minutes.

The procedure for the child participants was slightly modified to make the task more engaging. Before beginning any trials, children were given a practice story accompanied by practice questions, which did not have the same structure as the target questions. In addition to the calibration, a drift check procedure was employed at the beginning of each block. This involved fixation on a single point in the center of the screen, and it allowed re-calibration if necessary. This allowed children to take breaks between blocks if they were losing focus or having difficulty sitting still. The fixation cross was replaced with a cartoon character of a comparable size. Children had to fixate this character for 1000ms before the trial would move on to the question phase. Finally, children received positive feedback after every trial, and they received a sticker as a reward after each block. This encouraged children to pay attention to the stories and stay engaged in the task.

*Comprehension vocabulary measure.* Child participants' vocabularies were assessed using the Peabody Picture Vocabulary Test, Fourth Edition (PPVT™-4, Dunn & Dunn, 2007). This test was administered after the children completed the visual world eye tracking experiment.

### 2.1.4 Data Analysis

Because this task does not require participants to fixate on the relevant image, some participants fixated disproportionately on the blank areas of the screen. Including such trials could skew the fixation proportion data and mask relevant effects that occur when participants were looking at the images during the question. For a trial to be included in the analysis, the duration of fixations on any combination of the five pictures had to exceed 35% of the question duration.[2]

The overall time course data was arranged into 50ms (25 frame) windows. The window-by-window proportion of fixations to each of the pictures was calculated and the average proportion was plotted (see Figure 3 through Figure 6 below). As the verb region is the first critical region of interest and the length of the verbs varies across items, the x-axis, representing time in milliseconds, was aligned to this region such that the 0 time point on the x-axis represents the verb onset. The average length of the verb was 664ms. On these figures, the word regions are denoted by vertical, dotted lines. These lines are shifted by 200ms to account for the amount of time it takes to plan and execute a saccade (Altmann & Kamide, 2004; Matin, Shao, & Boff, 1993). These shifted lines represent the time intervals where potential effects of that region were expected.

As discussed earlier, our questions provide two opportunities for active gap filling, so there were two critical time intervals: the verb region and the direct object region. As in previous work (Omaki, 2010; Sussman & Sedivy, 2003), fixations on the target object during the verb region of *wh*-questions (i.e., before there is bottom-up evidence of a direct object gap) indicate active association of the filler with the verb. Upon hearing the direct object, however, this interpretation can be ruled out and an alternate gap position must be located. Therefore, fixations on the instrument during the direct object region of *wh*-questions indicate active association of the filler with the preposition, and the gap in the prepositional object position. The first region of analysis

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[2] To determine this criterion, the distribution of the duration of picture fixations per trial was examined for each age group individually. The point at which the distribution approached an asymptote was chosen as the cutoff percentage for each age group.

was the verb region after accounting for saccade planning and execution, i.e., 200ms to 900ms after the verb onset. The second region of analysis was the direct object region after accounting for saccades, i.e., 200ms to 1100ms after the direct object onset. This critical interval was realigned to the actual object onset for analysis.

For both analysis regions, the fixation data was aggregated into 50ms bins, and the empirical logit was calculated for each of these bins (Barr, 2008). The empirical logit is a quasi-logit transformation, which removes the effects of eye-movement based dependencies. The empirical logit data was fit to a linear mixed effect model with age group, question type, and time as fixed effects, random intercepts for participants and items, and random slopes for time. Additionally, separate planned pairwise comparisons for adults and children evaluated question type. The data from adults and children were isolated and individually fit to another linear mixed effect model with question type, and time as fixed effects and random intercepts for participants and items. Quadratic time (i.e., time squared) was included as a factor for the models examining fixations on the target object because of the expected pattern of fixations; participants fixate on the target object in the verb region, but look away towards the end of the verb region in anticipation of the next word region. The inclusion of time in the analyses allows us to examine the effect of our manipulations on two different features of the eye tracking record: the intercept and the slope. The intercept represents the likelihood of fixating the object of interest at the onset of the word region. The slope, on the other hand, describes how fixations on the image of interest change over the course of the region (i.e., how rapidly fixation proportions increase or decrease).

Before these analyses on the fixation data, an analysis to determine whether the children form a single population in terms of their active gap filling behavior or if there are distinct groups based on age was conducted as there is the potential for developmental differences. To do this, each child's individual predilection toward active gap filling was determined by comparing their average proportion of fixations on the target object during the verb in both question type conditions. A difference score for each participant was calculated by subtracting the proportion of fixations for the *yes-no* conditions from those for the *wh*-questions. A positive difference score indicated a preference for fixating on the object during the verb of *wh*-questions and was evidence of active gap filling. A negative difference score, on the other hand, indicated greater fixations on the object during the verb of *yes-no* questions. These difference scores were then correlated with age in months to determine whether it is appropriate to analyze the children as a single group. Difference scores for adults were also calculated, and participants with difference scores outside 2 standard deviations of the mean difference score for their group were excluded from further analyses.

## 2.2 Results

### 2.2.1 Question Accuracy

The adults answered 99% of the questions accurately. Eighteen adults were 100% accurate, while the remaining 4 adults gave a single incorrect answer to a filler question. The children had an overall accuracy of 97.6%, and all children were at least 85% accurate. The children's good offline performance suggests that they were attentive during the stories. Trials with incorrect answers were excluded from further analysis.

Adults answered all of the target questions correctly, but 11 of the children's target trials were excluded due to incorrect answers (11 out of 540, 2%).

### 2.2.2 Eye Movement Data

For the adults, 8 of the 240 target trials (~3%) were excluded for the duration of fixations on the pictures equaling less than the 35% criterion. For the children, 30 of 540 target trials were excluded (~6%) according to the same criterion. Including the 11 trials that were excluded for incorrect answers, a total of 41 target trials (~8%) were excluded for the children.

Consistent with the findings of other visual world studies (e.g., Altmann & Kamide, 1999; Sussman & Sedivy, 2003), both adults and children fixate on the pictures as they are named. The time course data from the adults replicates the findings of Omaki (2010). Figure 3 shows the adults' fixation proportions during the *wh*-condition, and Figure 4 shows the fixation proportions during the *yes-no* condition.

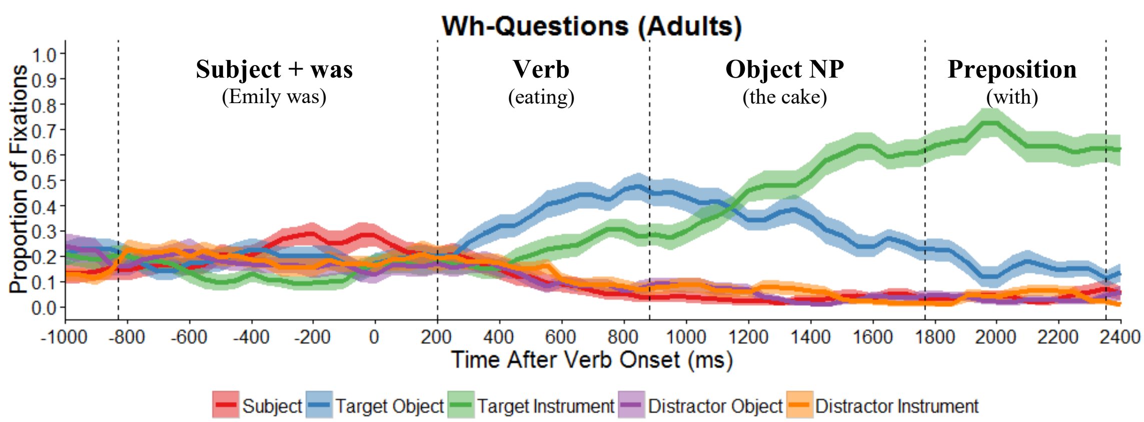


Figure 3. Adults' proportion of fixations to the displayed items in the *wh*-condition. Shaded areas indicate ±1 standard error.

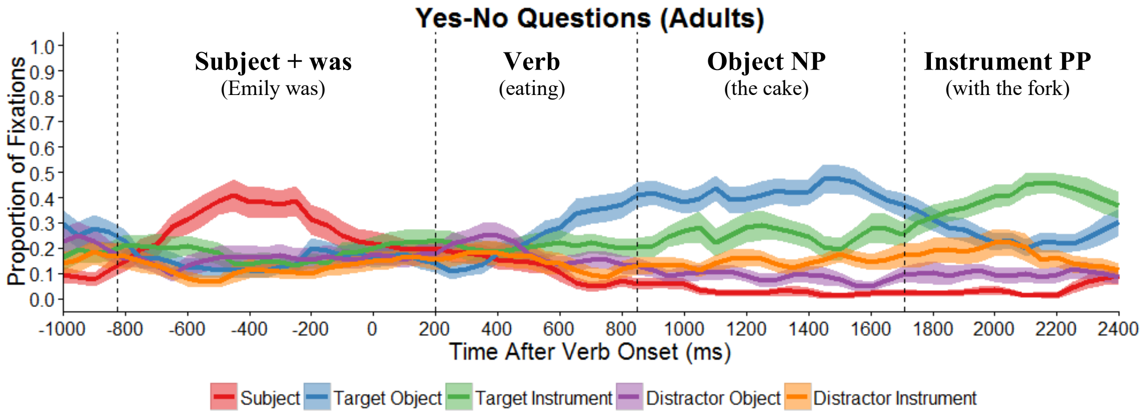


Figure 4. Adults' proportions of fixations to the displayed items in the *yes-no* condition. Shaded areas indicate ±1 standard error.

In the *wh*-condition (Figure 3), the fixations on the target object (e.g., *cake*) increased in the verb region. In the NP region, fixations on the instrument (e.g., *fork*) increased, which is the correct answer to the question. In the *yes-no* condition (Figure 4), fixations on the target object also increased in the verb region, but this increase is not as steep as it is in the *wh*-condition.

The time course data from the child participants is presented below. Figure 5 presents the proportion of fixations in the *wh*-condition, and Figure 6 presents the proportion of fixations in the *yes-no* condition.

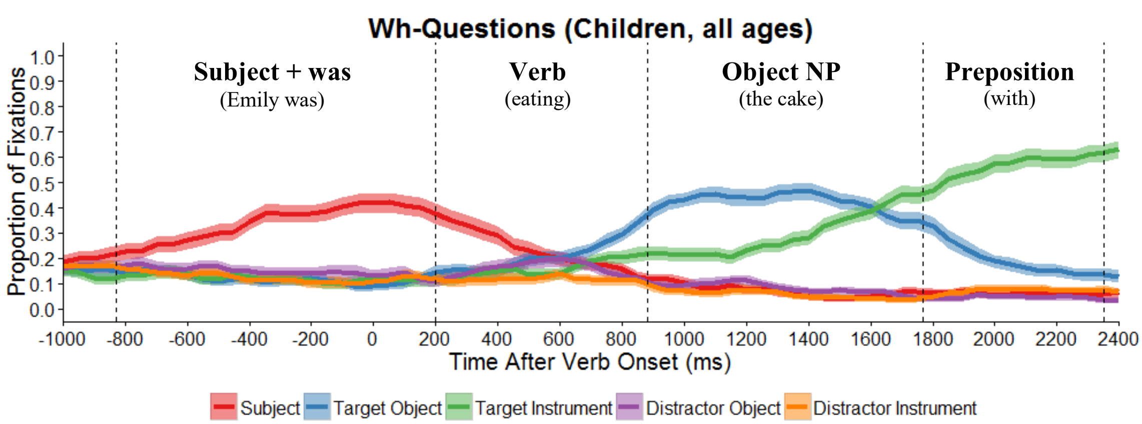


Figure 5. Children's proportions of fixations to the displayed items in the *wh*-condition. Shaded areas indicate ±1 standard error.

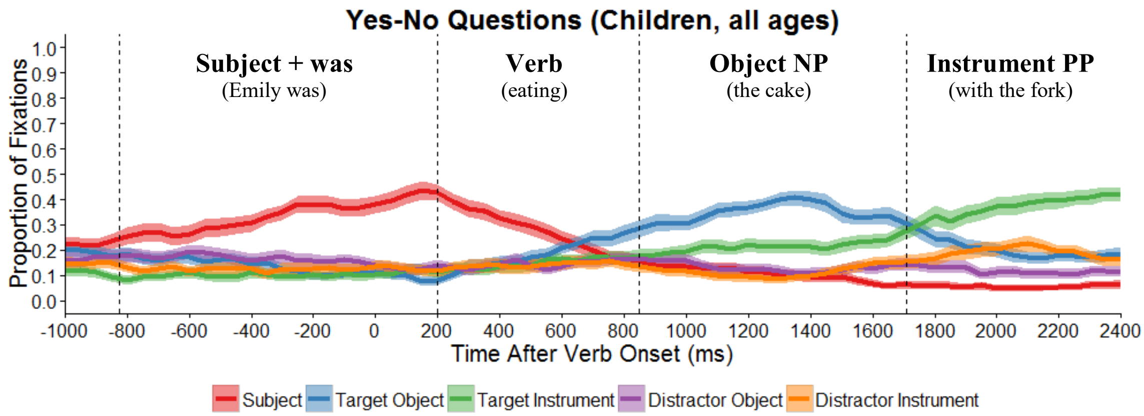


Figure 6. Children's proportions of fixations to the displayed items in the *yes-no* condition. Shaded areas indicate ±1 standard error.

Fixations on the target object (e.g., *cake*) in the *wh*-condition (Figure 5) increased some in the verb region, but this proportion of fixations is not as large or as early as it was for the adults. Fixations on the instrument (e.g., *fork*) increased during the noun region, which suggests that children recognize that the instrument is the correct answer before a missing argument is identified. The implications of this particular pattern of fixations on the instrument will be discussed below. In the *yes-no* condition (Figure 6), fixations on the target object again increased in the verb region, but this increase is not noticeably different from the *wh*-question condition. Unlike adults, children sustain fixations on the subject through much of the verb region in both conditions.

Interestingly, during the verb region, the difference between children's fixations on the target object in the *wh*- and *yes-no* questions conditions is not as large as it is for the adults. A large difference in fixations on the object across conditions was taken as evidence of active gap filling in both prior studies (Omaki, 2010; Sussman & Sedivy, 2003). The smaller difference for children raises the question of whether or not their pattern of eye movements differ based on question type. Figure 7 isolates the fixations on the target object in both question type conditions separated by age group.

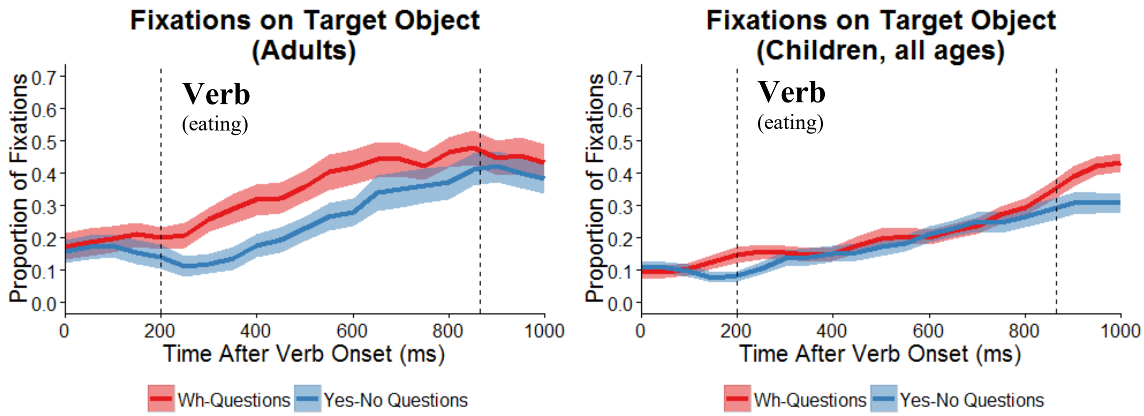


Figure 7. Adults' and children's proportion of fixations on the target object in both question type conditions. Shaded areas indicate ±1 standard error.

These figures indicate that the type of question affects the proportion of adults' fixations on the target object; adults fixate on the target object more often in the *wh*-question condition. Children's fixations on the object do not appear to appreciably differ. This suggests that children may not be actively searching for a gap position in this task.

*Difference scores.* The adults had a greater mean difference score (0.06, *SE* = 0.05) than children (0.02, *SE* = 0.03). Two adults and two children (a 5- and 6-year-old) were excluded from further analysis for having difference scores 2 standard deviations below the mean difference for their age group. To determine whether there were age effects, the children's difference scores were correlated with their age in months. Surprisingly, age in months is negatively correlated with difference scores, but this correlation is not significant ($R^2 = 0.02$, $p > 0.1$). As there is no significant effect of age, the children are collapsed into a single group for the remaining analyses.

*Statistical analyses.* The statistical analysis of the verb region is summarized in Table 2. The only effect on the intercept was an interaction of question type and age group ($\beta$ = -2.53, *SE* = 8.50, $p < 0.01$), which indicates that children had a greater difference in the question type intercept values compared to adults. For the slope terms, there was a significant effect of age group ($\beta$ = 3.84, $SE$ = 1.81, $p$ < 0.05); during the verb, the adults increased their fixations on the target object more quickly than children. There was also a significant interaction of question type and age group on the slope based on time ($\beta$ = 13.45, $SE$ = 3.48, $p$ < 0.001) and time squared ($\beta$ = -13.44, $SE$ = 3.48, $p$ < 0.001).

Table 2. Experiment 1 fixed effect summary for the overall linear mixed effect model (question type: *wh-* vs. *yes-no* questions; age group: adults vs. children).

| | **Estimate** | **SE** |
|---|---|---|
| *Intercept Effects* | | |
| Question Type | 5.66 | 4.25 |
| Age Group | -0.09 | 0.52 |
| Question Type x Age Group | -2.53 ** | 0.85 |
| Time | 3.78 *** | 0.95 |
| Time$^2$ | -1.32 | 0.81 |
| *Slope Effects* | | |
| Question Type x Time | -0.30 | 1.74 |
| Age Group x Time | 3.84 * | 1.81 |
| Question Type x Time$^2$ | 0.0006 | 1.61 |
| Age Group x Time$^2$ | -3.68 | 1.61 |
| Question Type x Age Group x Time | 13.45 *** | 3.48 |
| Question Type x Age Group x Time$^2$ | -13.44 *** | 3.22 |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

Planned pairwise comparisons for the adult data revealed no significant effects on the intercept, but a significant effect of the question type on the slope ($\beta$ = 7.06, $SE$ = 3.01, $p$ < 0.05). Adults increased their fixations on the target object more quickly during *wh*-questions compared to *yes-no* questions. Adults' higher proportion of fixations on the object in the *wh*-condition suggests that they are expecting a gap in the direct object position. Given the fact that there is no bottom-up evidence for a direct object gap during the verb and that the only difference between the conditions is the presence of a *wh-*

phrase, these results suggest that adults are actively associating the filler with the verb in this task.

Planned pairwise comparisons for the child data indicated a significant difference at the intercept ($\beta$ = 1.87, *SE* = 0.48, $p < 0.001$). Children were more likely to be fixating on the target object at the beginning of the verb region during *wh*-questions. Question type also had a significant effect on the slope ($\beta$ = -7.06, *SE* = 1.96, $p < 0.001$), but in the opposite direction. Children increased their fixations on the target object more quickly in the *yes-no* condition than in the *wh*-question. Essentially, these two effects counteract one another; because children were less likely to fixate on the target object at the beginning of the verb region during *yes-no* questions, their fixations on this image increased more quickly to reach the same proportion of fixations as in the *wh*-question condition.

Although children's fixations on the target object during the verb did not differ based on the type of question, these fixations began to diverge at the end of the region. Thus, fixations on the target object during the object NP region were examined for evidence of active gap filling in children. Figure 8 illustrates children's fixations on the target object in both question type conditions in the object NP region across all ages and within age groups based on age in years.

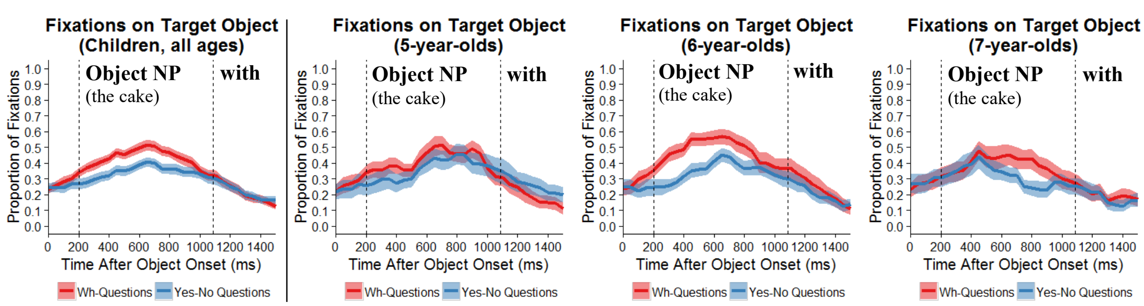


Figure 8. Isolation of children's proportion of fixations on the target object in the object NP region for both questions types separated by child age group. Shaded areas indicate ±1 standard error.

When examining the data for all children (far left in Figure 8), it appears that children were fixating more on the target object in the object NP region when there was a *wh*-filler. However, question type did not have a significant effect on either the intercept ($\beta$ = 0.40, *SE* = 0.39, $p > 0.1$) or the slope ($\beta$ = 0.85, *SE* = 1.36, $p > 0.1$). The qualitative difference is the result of age effects. Adding age in months as a fixed effect in the model reveals a marginal effect of age on the intercept ($\beta$ = 0.04, *SE* = 0.03, $p = 0.08$) and a significant interaction of question type and age in months ($\beta$ = -0.09, *SE* = 0.04, $p < 0.05$); at the onset of the object NP region, older children were more likely to be fixating on the target object in general and were more likely to be fixating on the target object during *yes-no* questions. Age in months has a significant effect on the slope ($\beta$ = -0.14, *SE* = 0.07, $p = 0.05$), but the directionality of the estimate indicates that older children increased their fixations on the target object more slowly as they aged. However, there is also a significant effect of the interaction of question type and age in months on the slope ($\beta$ = 0.30, *SE* = 0.13, $p < 0.05$) suggesting older children increased their fixations on the target object more quickly during *wh*-questions.

Further exploration of this age effect, however, reveals that it is not consistent across age groups. The individual age group plots in Figure 8 indicate that while 6-year-olds are demonstrating active gap filling late in the verb region and throughout the object NP region, this same pattern is not found for 7-year-olds. The unreliability of this age effect can also be seen in Figure 9, which plots children's difference score during the object NP region (fixation proportion on the target object during *wh*-questions – fixation proportion on the target object during *yes-no* questions). The correlation between difference score and age in months is not significant ($R^2$ = 0.0007, $p > 0.1$). The difference scores for 5- and 7-year-olds are fairly evenly distributed across the continuum from strongly preferring to fixate on the target object in *wh*-questions to strongly preferring to fixate on the target object in the *yes-no* questions. However, the 6-year-olds' difference scores cluster mostly above a difference score of zero. This suggests that most 6-year-olds preferred to fixate on the target object during the object NP of *wh*-questions, which is an indicator of active gap filling. There is no reason to believe active gap filling should demonstrate discontinuous development, so these findings are surprising. Reasons why 7-year-olds may not be demonstrating active gap filling is this task are discussed below.

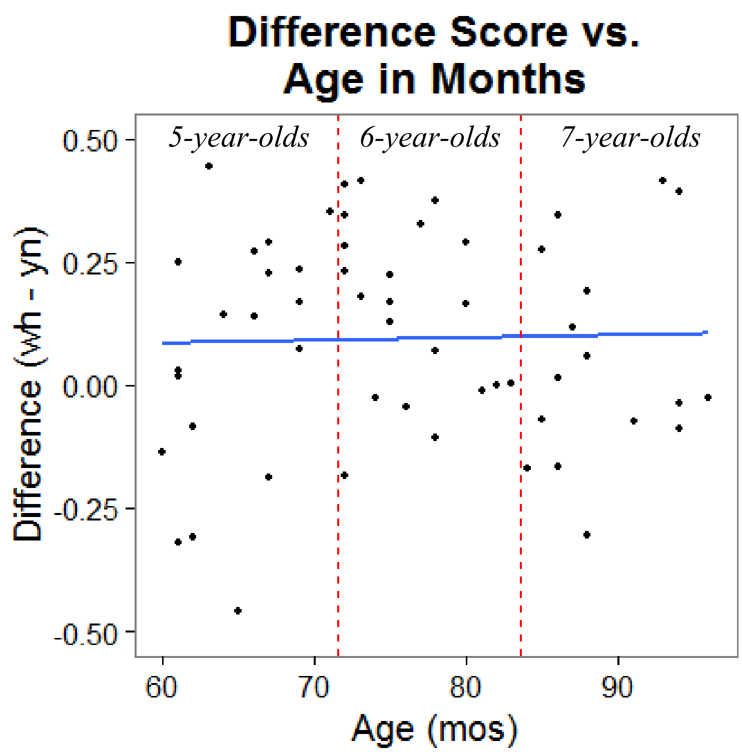


Figure 9. Scatterplot of target object fixation difference score (from the object NP region) versus age in months with the best fit line in blue. The red dashed lines indicate the age group divisions.

Children do not reliably demonstrate active gap filling in the verb region, as 6-year-olds are the only age group that shows any indication that they are consistently predicting a direct object gap. In the object NP region, however, they do predict an instrument gap like adults. During this region, children increase their fixations on the instrument associated with the verb more in the *wh*-question condition than in the *yes-no* question condition; this fixation pattern closely resembles that of adults. Figure 10 presents the fixations on the target instrument in both question type conditions separated by age group. These graphs are re-aligned such that 0ms represents the onset of the direct object (e.g., *the cake*), rather than the verb.

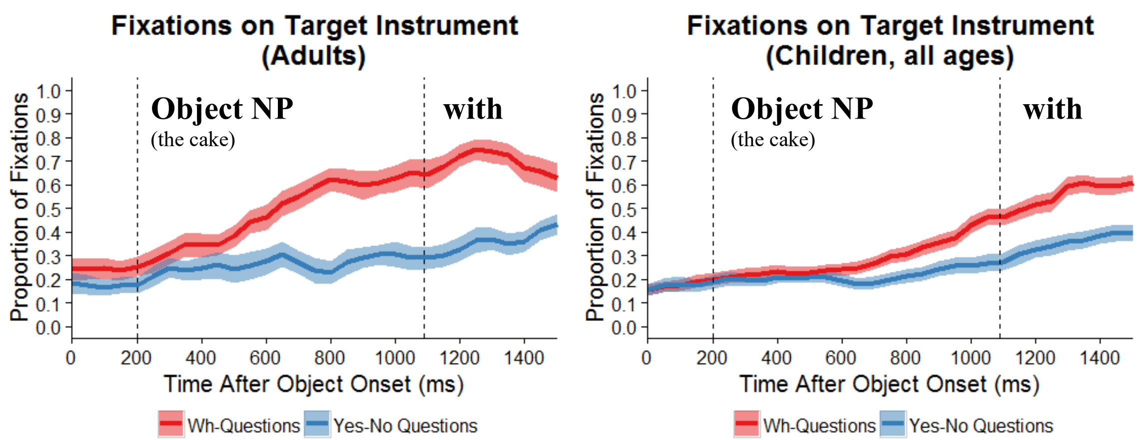


Figure 10. Isolation of adults' and children's proportion of fixations on the target instrument in both question type conditions. Shaded areas indicate ±1 standard error.

In the object NP region, adults were marginally more likely to be fixating on the target instrument at the onset of the object NP region ($\beta = 0.51$, $SE = 0.30$, $p = 0.09$). Question type had a significant effect on the slope ($\beta = 1.52$, $SE = 0.21$, $p < 0.001$); fixations on the target instrument during the *wh*-questions had a greater positive slope than during the *yes-no* questions in this region. Finally, the interaction of question type and age group also had a significant effect on the slope ($\beta = 1.16$, $SE = 0.42$, $p < 0.01$). Planned pairwise comparisons revealed that the slope of adults' fixations on the target instrument during the object noun phrase was significantly greater when the question contained a *wh*-filler ($\beta = 2.00$, $SE = 0.36$, $p < 0.001$). The slope of children's fixations on the target instrument were also significantly greater in this region in the *wh*-question condition ($\beta = 0.94$, $SE = 0.23$, $p < 0.001$), although the significant interaction on the slope in the overall model suggests that the difference between the conditions was smaller than that for adults. These results suggest that in the object NP region children are actively completing the dependency in the PP complement gap position in a manner similar to adults, even though they are immature in their ability to utilize the same active completion mechanism in the verb region.

*Vocabulary size measure.* Children had an average raw score (i.e., total number correct) of 131.2 words ($SE = 2.3$ words), an average standardized score of 121.1 words ($SE = 1.6$ words), and averaged in the 87$^{th}$ percentile ($SE = 2.5$ percentiles). Overall, the children were fairly high achieving; only 6 children scored beneath the 75$^{th}$ percentile for their age in years and months.

If children's active gap filling is mediated by their vocabulary size, then we expect a significant positive correlation between the likelihood to fixate the target object during the verb and the scores on the PPVT™-4. This likelihood is represented by individual's difference scores, so correlation analyses comparing these difference scores with both raw and standard scores on the PPVT™-4 were conducted. Both correlations were non-significant (difference score versus raw vocabulary score: $R^2 = 0.043$, $p > 0.1$; difference score versus standard vocabulary score: $R^2 = 0.014$, $p > 0.1$). Given these results, there appears to be no relationship between the use of an active dependency completion strategy and vocabulary size.

## 2.3 Discussion

The current study used visual world eye-tracking to investigate 5-to 7-year-olds' real time processing of filler-gap dependencies. For both *wh-* and *yes-no* questions and both age groups (adults vs. children), fixations on the target object during the verb region increased. This pattern of fixations was compatible with previous studies on verb-driven anticipatory fixations (e.g., Altmann & Kamide, 1999; Borovsky et al., 2012). Only adults demonstrated reliable active gap filling during the verb, however, because their proportion of fixations on the target object increased significantly more quickly when a *wh*-filler was present. As the only difference between the two question conditions is the presence of a filler-gap dependency in the *wh*-question, this pattern of eye movements was driven by the processing associated with the filler-gap dependency. Children's fixations on the target object, on the other hand, were similar during the verb region for both question types. This pattern of fixations suggests that children may not actively search for a direct object gap in the *wh*-question. Additionally, neither age nor vocabulary size seem to be reliably related to children's ability to utilize active dependency completion processes at the verb.

During the object NP region, however, both adults and children shifted their fixations to the target instrument. In the case of the adults, this finding suggests that they reinterpreted the *wh*-filler as associated with a prepositional object gap after encountering the overt direct object. At this point in the utterance, there was bottom-up evidence that the gap was *not* in the direct object position, but there was no such evidence for the prepositional object gap interpretation. Though children were immature in their association of the *wh*-filler with the verb, their fixations on the instrument during the direct object suggest that they were actively completing the prepositional object gap during the direct object region. This active gap filling of the prepositional object gap by children is discussed in more detail in the general discussion section.

Although our results at the verb suggest that children are not actively associating the filler with the verb, 6-year-olds' fixations on the target object during the object NP region provide some initial evidence for the development of adult-like active gap filling. Thus, it is possible that children are slower to complete the dependency and the verb region was not long enough to allow us to observe children's direct object gap predictions. The length of the verbs in this study was comparable to that in other child studies utilizing the visual world paradigm, however (600ms in Borovsky et al., 2012 versus 700ms in this study). Additionally, in the object NP region, children shift their fixations to the target instrument within 500ms after the region onset. This is evidence that the length of the verb is not a contributing factor in children's unreliable active gap filling.

# 3 Experiment 2 – Adult and child corpus analysis

Given that children did not reliably demonstrate active gap filling, the mechanism responsible for active gap filling needs to mature before children will be able to demonstrate adult-like processing behaviors. It is not clear, however, what knowledge children are missing. Active gap completion is only a useful mechanism if the first plausible gap position is also the most likely one. Adults and children, then, must know that direct object gaps are fairly common to actively complete the *wh*-dependencies in our task. It is possible, then, that the contrast between adult and child behaviors may be due to differences in distributional information. This is a plausible explanation if active gap filling can be attributed to models of parsing in which parsing biases are derived from probabilistic information (Jurafsky, 1996; Pickering, Traxler, & Crocker, 2000; Tanenhaus & Trueswell, 1995). If a distributional bias for direct object gaps is the basis of active gap filling, then knowledge of this distribution is required for active dependency completion, and experience with filler-gap dependencies may provide a mechanism for the development of active gap filling. Active completion of a dependency would be detrimental to processing speed if that completion occurs at a statistically unlikely gap position. On the other hand, active completion of a dependency at a statistically likely gap position would free up resources and ease processing. This suggests that a child must learn the distribution of the gap location in *wh*-questions, or filler-gap dependencies in general, before they can attempt to actively fill the gap at the first plausible position.

Additionally, previous work has suggested that children may be sensitive to the probability of a parse (Snedeker & Trueswell, 2004). In a visual world study, Snedeker and Trueswell presented commands including prepositional phrases. The verbs used in the study biased the interpretation of this PP as an NP modifier (*choose the cow with the stick*), an instrument (*tickle the pig with the fan*), or neither (equi-biased, *feel the frog with the feather*). Five-year-olds show the same sensitivities to these biases as adults. Children use the verb bias information to fixate on the target animal early in the complement NP of the prepositional phrase, even when multiple possible referents are available in the visual scene. These results suggest that 5-year-olds are capable of using distributional information like verb biases in their online processing decisions.

Given the experimental results and the discussion above, it is possible that children's non-adult-like behavior is due to exposure to a non-adult-like distribution of *wh*-questions. A corpus analysis of the distribution of gap positions in the input to adults has not previously been performed. Thus, this experiment examines the distribution of gap positions in the input to both adults and children and in the filler-gap dependencies that children produce.

## 3.1 Method

### 3.1.1 Corpus information

In order to determine the distribution of gap positions in adult filler-gap dependency production, I examined two naturalistic corpora of adult spoken language: the CallHome corpus (Kingsbury, Strassel, McLemore, & McIntyre, 1997) and a selection from the Switchboard corpus (Marcus, Santorini, Marcinkiewicz, & Taylor, 1999). These corpora were chosen because they consist of naturalistic, conversational speech between two adult participants. Filler-gap dependencies, especially *wh*-questions, are more likely to occur in a conversational environment than in non-conversational spoken or written corpora. The search was limited to syntactically parsed files; details about the corpora including the number of lines of examined speech are given in Table 3.

Table 3. Details of adult corpora used in the current study.

| Corpus | Number of Files Examined | Number of Lines of Speech |
|---|---|---|
| CallHome | 120 | 28,967 |
| Switchboard | 199 | 44,696 |

Because I am interested in filler-gap dependencies, the search was limited to questions and relative clauses. I used the Tregex utility (Levy & Andrew, 2006) to search the parsed trees for *wh*-phrases that indicate argument extractions: *who*, *what*, *which*, and *whose*. Sentences that utilize *that* as the relative clause head were also extracted. Relative clauses were included for the adults to increase the number of analyzed utterances because *wh*-questions were somewhat rare, even in the naturalistic corpora. These extracted sentences were then coded for embedding (matrix versus embedded question) and gap position (subject gap, object gap, or prepositional object gap). Echo questions were excluded.

While the adult corpus data simultaneously accounts for comprehension and production frequency, the same is not true for child corpus data where adult-produced, child-directed speech is used to quantify frequency of structures in comprehension. Thus, to determine the distribution of *wh*-questions that children hear and produce, the child-directed questions and child question productions from several child corpora were examined. These corpora are Abe (Kuczaj, 1977), Naomi (Sachs, 1983), Nina (Suppes, 1974), and Adam and Sarah from the Brown corpus (1973) and are available on CHILDES (MacWhinney, 2000). This resulted in 143,353 lines of child-directed speech and 158,194 lines of child speech. Table 4 provides additional details about the corpora including the children's age range and number of sessions.

Table 4. Details of CHILDES corpora used in the current study.

| **Corpus** | **Child** | **Age Range** | **Number of Sessions** | **Number of lines of Child-Directed Speech** | **Number of lines of Child Speech** |
|---|---|---|---|---|---|
| Brown (1973) | Adam | 2;3 – 4;10 | 55 | 26,688 | 46,743 |
| | Sarah | 2;3 – 5;1 | 139 | 46,192 | 38,096 |
| Kuczaj (1977) | Abe | 2;4 – 5;0 | 210 | 22,156 | 22,932 |
| Sachs (1983) | Naomi | 1;1 – 5;1 | 93 | 12,251 | 17,242 |
| Suppes (1974) | Nina | 1;11 – 3;11 | 56 | 35,965 | 33,181 |

For the analysis of child directed speech, only sentences with an argument *wh*-word (i.e., *who*, *what*, *which*, and *whose*) were extracted. Unlike the adults, sentences using *that* as a relative clause head were not extracted. The extracted sentences were then coded in the same way as the adult data. Echo questions were also excluded. Examples from Adam's corpus of the two critical gap positions, direct object and prepositional object gaps, are given in (6) and (7).

(6) *Matrix Questions*
a. I went for a walk tonight and *what* did I see? (direct object gap)
b. *what* are you crawling on? (prepositional object gap)

(7) *Embedded Questions*
a. do you remember *what* they're having for supper? (direct object gap)
b. can you tell Mr. Cromer *what* you rode on? (prepositional object gap)

Examples from Adam's speech of a direct object and prepositional object gap are given in (8) below.

(8) a. *what* I like? (direct object gap)
b. *what* else Santa got a boot on? (prepositional object gap)

## 3.2 Results

### 3.2.1 Adults

*All filler-gap dependencies.* Of the 73,663 lines of examined speech, 2,663 contained a filler-gap dependency (3.6% of the analyzed corpora). Table 5 presents the overall results of this analysis.

Table 5. Overall distribution of gap positions in the adult corpora.

| Corpus | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| CallHome | 390 | 767 | 177 | *1,334* |
| Switchboard | 680 | 519 | 130 | *1,329* |
| ***Overall*** | *1,070* ***(40.2%)*** | *1,286* ***(48.3%)*** | *307* ***(11.5%)*** | *2,663* |

Overall, there was a somewhat similar distribution of subject and direct object gaps (40.2% vs. 48.3%), while prepositional object gaps were fairly uncommon (11.5%). Because the gap positions of interest in the target *wh*-questions from Experiment 1 were post-verbal, a direct comparison of direct object and prepositional object gaps was warranted. Direct object gaps were about four times more frequent than prepositional object gaps (80.7% vs. 19.3%).

Because Experiment 1 focuses on questions and the overall analysis includes relative clauses, I also examined the subset of filler-gap dependencies within questions. Of the 2,663 filler-gap dependencies in the overall analysis, 995 were within questions (37.4%). Table 6 presents the results of this analysis.

Table 6. Distribution of gap positions in questions from the adult corpora.

| Corpus | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| CallHome | 264 | 466 | 101 | *831* |
| Switchboard | 38 | 107 | 19 | *164* |
| ***Overall*** | *302* ***(30.3%)*** | *573* ***(57.6%)*** | *120* ***(12.1%)*** | *995* |

Similar to the overall analysis, subject and direct object gaps were the most common (30.3% and 57.6% respectively), but direct object gaps were more common in questions than they were in the overall analysis (57.6% vs. 48.3%). Focusing on the post-verbal gaps, direct object gaps were once again much more frequent than prepositional object gaps (82.7% vs. 17.3%). The following section focuses on the filler-gap dependencies most similar to those in Experiment 1: *what* questions.

*What questions.* Of 73,663 lines of examined speech, only 546 contained a post-verbal *what* question (0.74% of the analyzed corpora). Table 7 presents the overall results of this analysis.

Table 7. Distribution of *what* questions in the adult corpora. *What* questions with a subject gap were removed from the total, because they are not relevant for the current study.

| Corpus | Object Gap | Prepositional Object Gap | Total |
|---|---|---|---|
| CallHome | 369 | 55 | 424 |
| Switchboard | 105 | 17 | 122 |
| ***Overall*** | *474* ***(86.8%)*** | *72* ***(13.2%)*** | *546* |

Of the 546 *what* questions, 474 contained a direct object gap; this accounts for 86.8% of the questions. Clearly, the distribution of *what* questions that adults produce when speaking with other adults skews toward direct object gaps. Across all three analysis levels (overall, questions, and *what* questions), direct object gaps were approximately 4 times more frequent than prepositional object gaps (~80% vs. ~20%). Thus, the distribution of gaps in adult's linguistic experience favored a direct object gap interpretation and supported active gap filling.

### 3.2.2 Input to children

*All wh-phrases.* Approximately 4.2% of the child-direct utterances in the examined corpora contained a filler-gap dependency with an argument *wh*-word (5,994 of 143,252 lines). Table 8 presents the distribution of gap positions within these utterances.

Table 8. Overall distribution of gap positions in the CHILDES corpora.

| Child | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| Abe | 93 | 362 | 37 | 492 |
| Adam | 310 | 664 | 122 | 1,096 |
| Naomi | 50 | 337 | 50 | 437 |
| Nina | 744 | 2,095 | 332 | 3,171 |
| Sarah | 372 | 348 | 78 | 798 |
| ***Overall*** | *1,569* ***(26.2%)*** | *3,806* ***(63.5%)*** | *619* ***(10.3%)*** | *5,994* |

Direct object gaps were the most frequent (63.5%), followed by subject gaps (26.2%) and prepositional object gaps (10.3%). Subject gaps were less common than in the adult analysis (26.2% vs. 40.2%), but this likely reflects the fact that relative clauses were included in the adult analysis by searching for uses of *that*. While some relative clauses were inevitably included in the analysis of the child-directed speech (e.g., those headed by *who*), they were not explicitly included in the search. Examining the post-verbal gaps, direct object gaps were much more frequent than prepositional object gaps (86.0% vs. 14.0%) as in the adult analysis. Table 9 presents an analysis that focuses on the subset of filler-gap dependencies that are within questions.

Table 9. Distribution of gap positions in questions from the CHILDES corpora.

| **Child** | **Subject** | **Direct Object** | **Prepositional Object** | **Total** |
|---|---|---|---|---|
| Abe | 90 | 318 | 35 | 443 |
| Adam | 292 | 583 | 106 | 981 |
| Naomi | 43 | 284 | 41 | 368 |
| Nina | 708 | 1,991 | 322 | 3,021 |
| Sarah | 357 | 328 | 75 | 760 |
| ***Overall*** | *1,490* ***(26.7%)*** | *3,504* ***(62.9%)*** | *579* ***(10.4%)*** | *5,573* |

The distribution of gap positions in child-directed questions was quite similar to that in the overall analysis; direct object gaps were the most frequent (62.9%), then subject gaps (26.7%) and prepositional object gaps (10.4%). The distribution of post-verbal gaps also resembled that of the overall analysis: 85.8% were direct object gaps while 14.2% were prepositional object gaps. The following section focuses on the types of child-directed utterances that most closely parallel the target questions from Experiment 1: *what* questions.

*What questions.* Of the 143,252 lines of child-directed speech in the examined CHILDES corpora, 3,737 of them contained a *what* question with a post-verbal gap. This accounts for 2.6% of child-directed utterances. The distribution of gap positions was very similar for matrix and embedded questions, so we collapsed over these structural types. In this experiment, all of our *wh*-questions had an overt competitor with the actual gap location: an overt prepositional phrase for the direct object questions and an overt direct object for the instrument questions. This kind of structure may be preferred by one type of question. Therefore, the *what* questions were also coded for the presence or absence of the competitor gap position. Table 10 presents the overall results of this corpus analysis.

Table 10. Distribution of *what* questions in several CHILDES corpora. *What* questions with a subject gap were removed from the total because they are not relevant for the current study.

| | **Direct Object Gap** | | | **Prepositional Object Gap** | | | |
|---|---|---|---|---|---|---|---|
| **Child** | *Overt PP* | *No PP* | *Total* | *Overt Object* | *No Object* | *Total* | **Total** |
| Abe | 73 | 231 | 304 | 13 | 15 | 28 | 332 |
| Adam | 174 | 444 | 618 | 37 | 81 | 118 | 736 |
| Naomi | 55 | 237 | 292 | 9 | 30 | 39 | 331 |
| Nina | 862 | 979 | 1,841 | 57 | 142 | 199 | 2,040 |
| Sarah | 40 | 234 | 274 | 9 | 15 | 24 | 298 |
| ***Overall*** | *1,204 (32.2%)* | *2,125 (56.9%)* | *3,329* ***(89.1%)*** | *125 (3.3%)* | *283 (7.6%)* | *408* ***(10.9%)*** | *3,737* |

Of the child-directed *what* questions, 89.1% of them were object questions. This distributional information was clearly skewed toward a preference for direct object gaps. For both gap locations, an overt competitor was less common. About thirty percent of questions with prepositional object gaps included an overt object noun phrase, while 36% of object questions included a prepositional phrase. Nonetheless, there was still a preference for direct object gaps among the questions with an overt competitor as in our stimuli (90.6% vs. 9.4%). There was a consistent finding across all three analysis levels (overall, questions, and *what* questions) – direct object gaps were more frequent than prepositional object gaps.

### 3.2.3 Child utterances

*All wh-phrases.* Of the 158,194 lines of examined child speech, 2,481 contained a filler-gap dependency with an argument *wh*-word (1.6% of the examined utterances). Table 11 presents the distribution of gap positions within children's speech.

Table 11. Overall distribution of gap positions in children's productions from the CHILDES corpora.

| Child | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| Abe | 134 | 493 | 127 | 754 |
| Adam | 202 | 697 | 253 | 1,152 |
| Naomi | 41 | 67 | 5 | 113 |
| Nina | 74 | 113 | 29 | 216 |
| Sarah | 40 | 174 | 32 | 246 |
| ***Overall*** | *491* ***(19.8%)*** | *1,544* ***(62.2%)*** | *446* ***(18.0%)*** | *2,481* |

Direct object gaps were the most frequent (62.2%), followed by subject gaps (19.8%) and prepositional object gaps (18.0%). This distribution was similar to the one calculated from child-directed speech (direct object gaps: 63.5%, subject gaps: 26.2%, prepositional object gaps: 10.3%, see Section 3.2.2). Examining just the post-verbal gaps, direct object gaps were quite frequent compared to prepositional object gaps (77.6% vs. 22.4%).

Table 12 focuses on the subject of children's filler-gap dependency productions that were within questions.

Table 12. Distribution of gap positions in children's questions from the CHILDES corpora.

| Child | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| Abe | 130 | 411 | 71 | 612 |
| Adam | 194 | 578 | 228 | 1,000 |
| Naomi | 41 | 61 | 5 | 107 |
| Nina | 70 | 99 | 17 | 186 |
| Sarah | 38 | 143 | 24 | 205 |
| ***Overall*** | *473* ***(22.4%)*** | *1,292* ***(61.2%)*** | *345* ***(16.4%)*** | *2,110* |

The distribution of gap positions in child questions closely resembled that from the overall analysis; direct object gaps were the most frequent (61.2%), then subject gaps (22.4%) and prepositional object gaps (16.4%). The distribution of post-verbal gaps was also similar to that from the overall analysis: 78.9% were direct object gaps while 21.1% were prepositional object gaps. The following section analyses productions closest to the targets: *what* questions.

*What questions.* Of the 158,194 lines of child speech in the examined CHILDES corpora, 1.0% contained a *what* question with a post-verbal gap (1,597 utterances). As in the child-directed speech analysis, questions with an overt competitor for the gap position, i.e., an overt prepositional phrase for the direct object questions and an overt direct object for the instrument questions, may be preferred by one type of question. Therefore, as in the earlier corpus analysis, the *what* questions were coded for the presence or absence of the competitor gap position. Table 13 presents the overall results of this analysis.

Table 13. Distribution of *what* questions in children's productions from several CHILDES corpora. *What* questions with a subject gap were removed from the total because they are not relevant for the current study.

| | **Direct Object Gap** | | | **Prepositional Object Gap** | | | |
|---|---|---|---|---|---|---|---|
| **Child** | *Overt PP* | *No PP* | *Total* | *Overt Object* | *No Object* | *Total* | **Total** |
| Abe | 22 | 381 | 403 | 24 | 44 | 68 | 471 |
| Adam | 35 | 537 | 572 | 22 | 196 | 218 | 790 |
| Naomi | 4 | 57 | 61 | 2 | 3 | 5 | 66 |
| Nina | 18 | 78 | 96 | 3 | 14 | 17 | 113 |
| Sarah | 3 | 133 | 136 | 2 | 19 | 21 | 157 |
| ***Overall*** | *82 (5.1%)* | *1,186 (74.3%)* | *1,268* ***(79.4%)*** | *53 (3.3%)* | *276 (17.3%)* | *329* ***(20.6%)*** | *1,597* |

Of the child *what* question productions, 79.4% of them contained a direct object gap. As in the overall and question analysis, the distributional information was clearly skewed toward direct object gaps. Additionally, overt competitors for the actual gap position were uncommon. Only about 7% of the *what* questions with a direct object gap also contained an overt prepositional phrase (82 out of 1,268). Overt direct objects in prepositional object gap questions are somewhat more common at 16% (53 out of 329). Nonetheless, there was still a preference for direct object gaps when comparing only those utterances with a direct competitor (60.7% vs. 39.3%).

## 3.3 Discussion

Both adults and children were exposed to similar distributions of post-verbal gaps in their input: approximately 80% direct object gaps versus about 20% prepositional object gaps. While it was possible that the distribution of gaps in children's productions differed from the distribution that they were exposed to in the input from adults, children produced gap positions in approximately the same proportions as they were exposed to in their input (i.e., approximately 80% direct object gap production and 20% prepositional object gap production). This bias is consistent with a probabilistic account of active gap filling; a direct object gap is predicted during real time sentence comprehension because it is the most probable gap position. Accordingly, it seems reasonable to expect that this distributional information would lead children as young as 5-years-old to demonstrate adult-like active gap filling at the verb region. Thus, a distributional bias is clearly not the sole basis of the difference between adults and children.

# 4 Overall Discussion

In the visual world eye tracking study, children did not actively associating the filler with the verb, though 6-year-olds revealed some evidence for active gap filling in the object NP region. Although 6-year-olds seem to demonstrate active gap filling in the object NP region, active gap filling in this region was not found for 7-year-olds. While this may appear to be a case of discontinuous development, alternative explanations for the 7-year-olds fixation data suggest that this is not the case. First, the visual world eye tracking experiment was designed to be appealing to 5-year-olds. Because of this, many 7-year-olds found the task boring and tedious and had difficulty remaining engaged. Most 6-year-olds, on the other hand, remained engaged throughout the task. If 7-year-olds lack of active gap filling can be attributed to their level of engagement, then a study more tailored to their interest level may reveal direct object gap predictions in the object NP region (like 6-year-olds) or even active gap filling at the verb (like adults).

Alternatively, it is possible that 7-year-olds are more aware of the potential for a gap in the prepositional object position. Knowledge that many gap positions are possible may lead to weaker predictions about gap positions; if 7-year-olds knows that a prepositional object gap is possible, they may not have confidence in the distributional information indicating that direct object gaps are the most frequent gap position. Were this the case, they may implicitly inhibit their gap predictions until they are more certain about the gap position (i.e., after the object NP has been processed). Essentially, this account suggests that the more a child knows, the less certain they are about their predictions, at least until the underlying distribution gap positions is solidified. This account suggests that young children who know very little about filler-gap dependencies may demonstrate active gap filling due to this lack of knowledge.

## 4.1 Comparison to other developmental active gap filling studies

The results of our visual world eye tracking study appear to be inconsistent with the results of other studies that have examined children's processing of *wh*-questions and found evidence for active gap filling in five-year-olds. Love (2007) reported that children were faster to make an edibility judgment immediately following the offset of a verb when that judgment was on a picture associated with the filler. She argued that this facilitation effect indicated that the filler was reactivated during the verb in anticipation of encountering the gap location in the direct object position. Omaki et al. (2014) found that English- and Japanese-speaking children have the same interpretation preferences as adults for ambiguous biclausal questions like *Where did Emily tell someone that she hurt herself?* Children prefer to interpret the gap as associated with the first available verb whether it is the main clause verb as in English or the embedded clause verb as in Japanese. Additionally, Japanese children were unable to reanalyze their initial interpretation when the potential gap site in the embedded clause was filled. These results were taken to indicate that children are associating the *wh*-filler with the first available verb and that this association occurs before bottom-up information on the gap location is available.

It is possible that the difference in gap position ambiguity between our questions and Omaki et al.'s is at fault. As described earlier, Omaki et al.'s (2014) gap ambiguity was cross-clausal (e.g., *Where did Lizzie tell someone _?_ [that she was gonna catch butterflies _?_ ]?*), while the ambiguity in Experiment 1 was within a single clause (e.g., *Can you tell me [what Emily was eating (_?_) the cake with _?_ ]?)*. Children may be biased to complete a filler-gap dependency within the first available clause. Thus, they may complete the dependency in the first clause not because they predicted this gap position, but because there are no other competing gap positions within this clause.

There is some evidence in support of this explanation in Omaki et al.'s findings in Japanese. Because Japanese is a head-final language, the embedded clause of biclausal questions is first linearly, and Japanese adults and children prefer to associate the filler with the embedded clause verb for this reason. Omaki et al. report that if the association of the filler with the embedded verb is syntactically blocked by a locative PP (e.g., translated to English: *Where did Lizzie tell someone that she was gonna catch some butterflies at the park?*), Japanese-learning children continue to interpret the filler as associated with the embedded verb. However, when there was no plausible interpretation for the filler-embedded verb association, they were able to interpret the filler as associated with the main verb. While these findings could be interpreted as active gap filling at the first available verb position, they are also compatible with a strong bias toward completing the dependency within a single clause.

## 4.2 Active gap filling at the object NP

Although children's active gap filling at the verb is immature, they do predict the prepositional object gap during the object NP region. During the object NP region of *wh*-questions, children increase their fixations on the instrument associated with the verb, exactly like the adults. This suggests that in the object NP region children may be actively completing the dependency in the PP complement position, even though they are unable to use this same strategy in the verb region. This may be a case of delayed or conservative generation of syntactic predictions.

Children's ability to generate gap predictions later in the utterance may be related to the number of plausible gap positions in the target *wh*-questions. Specifically, children may require greater confidence than adults in an interpretation before committing to it. Active completion of the *wh*-dependency indicates a level of certainty that associating the filler with a direct object gap will result in the correct interpretation. The target *wh*-questions used in this study have two plausible gap locations: the complement of the verb, e.g., *Can you tell me what Emily was eating?*, or the complement of the preposition, e.g., *Can you tell me what Emily was eating the cake with?* Because these two options are available, children may not be confident enough in the direct object interpretation to attempt to complete the dependency during the verb. After the direct object is processed, however, the only remaining plausible gap location is the complement of the preposition. Children, then, can be very confident that this interpretation is the correct one, and this high level of confidence may lead to an active completion of the dependency.

Children notably have difficulty revising their initial interpretations when later information unambiguously indicates an alternative interpretation (e.g., Choi & Trueswell, 2010; Omaki et al., 2014; Trueswell et al., 1999). For example, when comprehending the sentence *Put the frog on the napkin in the box*, both 5-year-olds and adults initial interpreted the first prepositional phrase (*on the napkin*) as the destination of the action (Trueswell et al., 1999). When adults processed the second PP (*in the box*) which was the actual destination, they were able to revise their interpretation of the first PP as a modifier of the NP *the frog* and complete the target action. On the other hand, many children did not re-interpret the first PP, and this was reflected in their act out errors; they regularly moved the frog to the napkin and then to the box (a "hopping" action) or moved the frog to the napkin and left it there.

Given this difficulty with revision, a conservative approach may prevent children from committing to an incorrect interpretation from which they cannot recover. Future work can test this account by varying the context such that two gap locations are not plausible. For example, if the eating cake action did not include a fork, children could be more confident that a *what* question about this event will have an object gap. Given their increased confidence in the direct object gap interpretation, children may be willing to utilize an active completion strategy upon processing the verb. Children's confidence in their predictions may also be related to the strength of the filler-gap dependency representation. If the representation of the link between the filler and the gap is strong, children may be more willing to generate gap predictions. This possibility will be explored in depth in Chapter 5 in light of this finding and additional developmental findings presented in Chapter 4.

## 4.3 Distributional analysis

The results of the corpus analysis suggest that children (and adults) have the appropriate distribution of direct object and prepositional object gap questions to support active gap filling. This is strong evidence against probabilistic parsing accounts and suggests that they may not be an accurate representation of real time processing procedures. However, while distributional information is not sufficient to explain children's active gap filling behavior, it does accurately predict other attested sentence processing phenomena. Levy (2008) reviews many of these examples, which include an account of eased processing of sentence final verbs with an increasing number of dependents, the facilitatory effect of some ambiguous contexts, and the preference to interpret ambiguous noun phrases a subjects. Levy admits that there are empirical difficulties for the theory, one of which is the processing difficulties associated with object relative clauses. He suggests here and elsewhere (2008; Levy et al., 2013) that probabilities may only explain local processing effects and that long distance dependencies are processed in a fundamentally different fashion. The findings from this chapter provide additional evidence in favor of this suggestion.

Alternatively, it is possible that children do not use all of the distributional information available to them in their parsing decisions. Despite the fact that they are able to make use of some statistical regularities in processing (e.g., verb biases driving PP-attachment decisions, Snedeker & Trueswell, 2004), it may be the case that children cannot use distributional information in long-distance dependency processing. Given the potential benefits of using this information (e.g., more efficient and faster processing), ignoring the input distribution is not a particularly rational processing decision unless there are other constraining factors (for discussions of similar arguments, see Howes, Lewis, & Vera, 2009; Lewis, Shvartsman, & Singh, 2013). It has been argued that maintaining long-distance dependencies is costly for memory resources (Chen, Gibson, &

Wolf, 2005; Gibson, 1998, 2000). Because cognitive abilities develop throughout childhood (e.g., Gathercole & Baddeley, 1993), the children in this study may not have had the capacity to maintain the filler-gap dependency in memory and simultaneously incorporate the distributional information (see Grodner, Gibson, & Tunstall, 2002). However, such an account predicts that active gap filling should develop as memory resources grow, and we did not find a reliable effect of age on active gap filling in the verb or the object NP regions.

# CHAPTER 3 – SYNTACTIC ADAPTATION OF GAP PREDICTIONS

## 1 Introduction

The developmental investigation of active gap filling from Chapter 2 suggests that a probabilistic account is not sufficient to account for children's non-reliable syntactic predictions. Children are not consistently predicting a direct object gap, despite the fact that they are exposed to the same distribution of post-verbal gaps as adults. Evidence from the adult sentence processing literature, however, suggests that parse probabilities do play a role in sentence comprehension (e.g., Fine, Jaeger, Farmer, & Qian, 2013; Fine, Qian, Jaeger, & Jacobs, 2010; Hale, 2001; Jaeger & Snider, 2013; Levy, 2008; Levy, Fedorenko, & Gibson, 2013; Linzen & Jaeger, 2015; Myslín & Levy, 2016). Thus, it would be hasty to conclude that the distribution of syntactic structures does not affect syntactic predictions on the basis of this developmental study alone. This chapter examines the effect of local language experience, i.e., the distribution of gap positions in the preceding context, on filler-gap dependency processing.

In the speech perception literature, it has been demonstrated that listeners can temporarily adapt their phonetic categorizations to variable acoustic input (Kraljic & Samuel, 2007). Listeners adapt after limited exposure to non-native speech (Bradlow & Bent, 2008; Samuel & Larraza, 2015), dialect variants (Dahan, Drucker, & Scarborough, 2008; Kraljic, Brennan, & Samuel, 2008; Sumner & Samuel, 2009), and acoustically distorted speech (Davis, Johnsrude, Hervais-Adelman, Taylor, & McGettigan, 2005). For example, Kraljic & Samuel (2007) replaced /s/ for one speaker and /ʃ/ for another speaker with a sound ambiguous between the two (/?sʃ/). Participants generated speaker-specific categories for the ambiguous sound after only 10 trials. During a post-exposure categorization task, participants were more likely to categorize the ambiguous sound as falling within the trained category based on the particular speaker; in other words, if the female speaker produced /s/ as the ambiguous sound, /?sʃ/ was categorized as an /s/ when the speaker was female. Likewise, if the male speaker produced /ʃ/ as /?sʃ/, the ambiguous sound was categorized as an /ʃ/ when the speaker was male. This phenomenon has been modeled using Bayesian belief-updating (Kleinschmidt & Jaeger, 2011, 2015).

Recently, adaptation methodologies from speech perception research have been extended to other linguistic domains, namely expectation of syntactic structure (Fine et al., 2013; Jaeger & Snider, 2013; Linzen & Jaeger, 2015; Myslín & Levy, 2016), quantifier meaning (Yildirim, Degen, Tanenhaus, & Jaeger, 2013), and informativity of referring expressions (Pogue, Kurumada, & Tanenhaus, 2016). For example, work has demonstrated semantic adaptation to speaker-specific uses of the quantifiers *many* and *some* (Yildirim et al., 2013). Participants were shown how different speakers would describe bowls of green and blue candies; in the critical "Most Ambiguous Quantity" scene, 13 of the candies were green and 12 of the candies were blue. One speaker described this scene as "Most of the candies are green" while another described it as "Some of the candies are green." Participants adapted to speaker specific quantifier usage. They accepted uses of *some* or *most* consistent with the scenes and speakers to which they were exposed. Additional work has shown that biases in real time ambiguity resolution can be altered by manipulating the probability of the competing structures in the input (Fine & Jaeger, 2013; Fine et al., 2013; Jaeger & Snider, 2013; Myslín & Levy, 2016). Given the interest in filler-gap dependencies, the focus here is on the latter effects: adaptation to the usage of syntactic structures.

## 1.1 Previous work on syntactic adaptation

A major source of evidence for comprehenders' ability to generate and update expectations based on their previous linguistic input and the current linguistic environment comes from the extensive syntactic priming literature. Many studies have demonstrated that speakers tend to repeat syntactic structures across utterances (Bock, 1986). This tendency toward repetition is usually investigated in one of two environments. One line of investigation focuses on the immediate effect of the structure of a single prime sentence on the structure of a single subsequent target sentence. The alternative line of investigation examines the cumulative effects of experience with syntactic structures on the structure of a target sentence.

### 1.1.1 Immediate priming effects

Several language production studies have shown that producers tend to immediately reuse the syntactic structure of previous utterances (Bock, 1986; Bock & Loebell, 1990; Branigan, Pickering, & Cleland, 2000; Branigan, Pickering, Stewart, & McLean, 2000; Pickering & Branigan, 1998). In a classic study, Bock (1986) demonstrated that passives and forms of the dative alternation, double object datives versus prepositional object datives, could be primed. Participants were more likely to produce a passive structure when the prime was a passive than when the prime was active (although passives were still only produced 20% of the time). Similarly, participants were more likely to produce a dative matching the form of the previous sentence; double object datives (DO: *A rock star sold an undercover agent some cocaine*) were 22% more likely to be produced after another DO dative, and the production of prepositional object datives (PO: *A rock star* *sold some cocaine to an undercover agent*) increased by 23% when the prime was also a PO dative.

Unlike production priming, the evidence for immediate comprehension priming is less robust. Many studies only find priming effects in comprehension if the prime and the target share a verb (Arai, van Gompel, & Scheepers, 2007; Branigan, Pickering, & McLean, 2005). However, evidence for comprehension priming independent of verb repetition is beginning to accrue (Hutton & Kidd, 2011; Scheepers & Crocker, 2004; Thothathiri & Snedeker, 2008a; Traxler, 2008). Thothathiri and Snedeker (2008a) examined priming effects on real time comprehension of the dative alternation. Participants were instructed to interact with the objects in a visual scene using either a DO or PO dative structure. In the targets, the form of the noun phrase following the verb induced a temporary argument structure ambiguity (DO: *Show the **hor**se the book*; PO: *Show the **hor**n to the dog*). Across three experiments, participants primed with DO datives looked more toward the animate recipient than the inanimate theme during the ambiguous region and vice versa for participants primed with PO datives. These results demonstrate that participants expected dative sentences to duplicate the structure of the previous dative sentence, which in turn influenced their processing and interpretation of temporarily ambiguous NPs. The work on prime-target pairs suggests that the structure of a prior utterance can affect both the production and comprehension of a subsequent utterance. Thus, experience with syntactic structure can have an immediate effect on processing behavior.

### 1.1.2 Cumulative priming effects

In contrast to the work on immediate priming effects, other studies have demonstrated that the tendency for structural repetition extends beyond the following utterance (Bock & Griffin, 2000; Kaschak, 2007; Kaschak, Kutta, & Coyle, 2014; Kaschak, Loney, & Borreggine, 2006). Kaschak and colleagues (2006) demonstrated that recent experience with double object (DO) and prepositional object (PO) datives affected the strength of structural priming in their written sentence productions. Participants completed sentences skewed toward DO dative completions (*Meghan gave her mother…*), PO dative completions (*Meghan gave the doll…*), or either DO or PO dative completions (*The soldier gave…*). During a "Recent Experience" phase, participants completed either an equal number of DO and PO constructions or only one of the constructions. Those with equal experience with the two dative completions were strongly primed. However, when participants' recent experience was skewed toward a single construction, priming was greatly reduced for the alternate structure. This finding suggests that there are cumulative effects of language experience on structural priming; specifically, the relative frequency of the structure in recent experience affected the strength of priming.

A similar line of work examines whether comprehenders adapt their expectations about upcoming syntactic structure after exposure to *a priori* unexpected structures (Fine & Jaeger, 2013; Fine et al., 2013, 2010; Kamide, 2012; Kaschak & Glenberg, 2004; Linzen & Jaeger, 2015; Wells, Christiansen, Race, Acheson, & Macdonald, 2009). Fine et al. (2013) explored whether the comprehension of temporary syntactic ambiguities changed based on repeated exposure to these structures. In particular, they examined the temporary ambiguity that is generated by the past participle form of certain verbs, which can be used both as a main verb (1a) and as the verb in a reduced relative clause (1b).

(1) The experienced soldiers…
    a. *Main verb:* …warned about the dangers before the midnight raid.
    b. *Reduced relative:* …warned about the dangers conducted the midnight raid.

In Fine et al.'s Experiment 2, a group of participants was exposed to 16 sentences with reduced relative clauses like those in (1b).[3] Normally, the main clause / reduced relative ambiguity leads to a significant reading time slowdown on the disambiguating region, *conducted the midnight* in (1b), in sentences with reduced relative clauses. Participants exposed to reduced relative clauses demonstrated reduced processing difficulty on the disambiguating region in ambiguous sentences including this structure compared to a control group that was exposed to filler sentences.

Fine et al. suggest that these results indicated adaptation to the distribution of syntactic structures in the input. When reduced relatives were more frequent in the input, participants updated their expectations about the probability of a reduced relative continuation upon encountering a verb in its past participle form. Increased exposure to reduced relatives lead to an increased expectation of that structure in the future and decreased processing difficulty when it was encountered. A similar adaptation effect was demonstrated with the direct object / sentential complement ambiguity (Fine et al., 2010; Myslín & Levy, 2016). Because language experience can affect future structural selection processes, it seems reasonable that distributional information about syntactic structures might also have an affect on predictive processing.

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[3] Only half of these sentences (8 out of 16) were ambiguous. The other half included an overt relative clause marker, i.e., *that*, which rendered the sentences unambiguous (*The experienced soldiers that warned about the dangers conducted the midnight raid.*). These count as exposure to reduced relative clauses, though they are easier to process than the ambiguous sentences because they prevent misanalysis of the past participle verb as a main clause verb and subsequent reanalysis.

## 1.2 The current studies

The cumulative priming and syntactic adaptation effects suggest that language experience has a rapid impact on adult's sentence processing behaviors. This link between experience and processing makes the lack of a distributional effect on children's active gap filling (see Chapter 2) particularly surprising. While the distribution of gap positions in adults' input is compatible with their filler-gap dependency parsing decisions (i.e., direct object gap predictions), there has been no explicit demonstration of the link between the distribution of gap positions in the input and the generation of syntactic predictions. The first two studies (Experiments 3 and 4) aim to address this question by examining whether adults adapt their syntactic predictions in filler-gap dependency processing. In other words, do adults adapt their gap predictions to reflect the distribution of gap positions in their input?

Also, previous syntactic adaptation effects have only been demonstrated within a tightly controlled laboratory environment. It is possible that these effects do not represent natural parsing behavior, but rather an experiment specific technique. This could explain why children in Experiment 1 were unable to use the available distributional information to generate direct object gap predictions. If syntactic adaptation is the result of an experiment-specific strategy, then it would not be surprising that distributional information derived from years of language experience might not have an effect on active gap filling. Experiment 5 tests this hypothesis by presenting the distributional information in a different experimental environment than the test phase.

## 2 Experiment 3 – Blocked adaptation: filled direct object gap

Experiment 3 utilizes a between-subject blocked design adapted from Fine et al.'s (2013) second experiment to examine whether real time filler-gap dependency processing procedures adapt to the statistics of the input. This particular implementation was chosen because Fine et al. demonstrated effects of language experience on structural expectations during comprehension rather than on which structural alternative was produced.

As was noted above, syntactic adaptation crucially relies on the distribution of relevant syntactic structures. Therefore, the adaptation of syntactic predictions in filler-gap dependency processing should rely on the relative frequency of gap positions. The adult corpus analysis presented in Experiment 2 focused on the overall distribution of gap positions in filler-gap dependencies, the distribution in questions, and the specific distribution for *what* questions. The following experiments will examine relative clause structures, so Table 14 presents the subset of the adult corpus data utilizing this structure.[4]

Table 14. Distribution of gap positions in adult's relative clauses.

| Corpus | Subject | Direct Object | Prepositional Object | Total |
|---|---|---|---|---|
| CallHome | 126 | 301 | 76 | 503 |
| Switchboard | 642 | 412 | 111 | 1,165 |
| ***Overall*** | 768 **(46.0%)** | 713 **(42.8%)** | 187 **(11.2%)** | 1,668 |

Similar to the overall distribution, subject and direct object gaps accounted for approximately 90% of gaps within relative clauses. Subject gaps were more frequent than object gaps (46.0% vs. 42.8%), and this slight preference for subject gaps is consistent with the finding that subject relative clauses are easier to process than object relative

[4] See Chapter 2, Section 3.1.1 for additional details on the adult corpora.

clauses (e.g., Gibson, 1998, 2000; Grodner, Gibson, & Tunstall, 2002; Levy et al., 2013; Staub, 2010).

Focusing on post-verbal gap positions (i.e., direct object and prepositional object gaps), which are the critical ones for active gap filling, direct object gaps were more frequent in relative clauses than prepositional object gaps (79.2% vs. 20.8%). Thus, the current experiments are justified in assuming that the input favors direct object gaps in relative clauses (compared to prepositional object gaps). Given this distribution, direct object gaps are *a priori* highly probable in the syntactic structures used in this experiment. Thus, participants' baseline preference should be to predict direct object gaps. This experiment attempts to alter this parsing bias by exposing participants to input skewed toward prepositional object gaps.

## 2.1 Method

### 2.1.1 Participants

Sixty native English speakers from the Johns Hopkins University community participated and were paid $10 or received course credit.

### 2.1.2 Design and Materials

The design of this study is a two block version of Fine et al.'s (2013) Experiment 2. Table 15 describes the blocked design of Experiment 3. The first block consisted of 24 sentences and was used to manipulate the distribution of gaps. There were three groups of participants defined by the input they received in this exposure block: 1) the PO-gap exposure group read sentences with PO-gaps, which increased the probability of these gaps, 2) the DO-gap exposure group read sentences with direct object gaps, which matched participant's *a priori* distribution of gap positions, and 3) the filler exposure group received neutral input (i.e., sentences that did not contain a filler-gap dependency). The second block was identical for all groups and consisted of 24 target sentences randomly interspersed with 48 fillers.

Table 15. Design of Experiment 3.

| *Group (Exposure Type)* | *Block 1 (Exposure)* | *Block 2 (Experimental)* |
|---|---|---|
| PO-gap exposure | 24 NP-fronting filled object gap sentences (2a) | 24 target pairs (2) + 48 fillers |
| DO-gap exposure | 24 direct object gap sentences (3) | |
| Filler exposure | 24 fillers | |

The target sentences in the experimental block consisted of filled gap sentences (2a); these sentences have prepositional object gaps, which were preceded by a direct object NP.

(2) a. *NP-fronting:* The suitcase **that** the stealthy, wanted thief stole the precious jewels from __ was full of sentimental items.
b. *PP-fronting:* The suitcase **from which** the stealthy, wanted thief stole the precious jewels __ was full of sentimental items.

The NP-fronting target sentences were compared to PP-fronting sentences in which the preposition was pied-piped with the *wh*-phrase (2b), which are incompatible with a direct object gap (Lee, 2004; Wagers & Phillips, 2014). If the parser actively completes the dependency, reading time should increase on the direct object of the NP-fronting condition (2a) compared to the PP-fronting condition (2b).

Filled gap sentences (2a) were also used in the PO-gap exposure block. Sentences in the DO-gap exposure block have a similar structure to (2a), but contain a direct object gap followed by a prepositional phrase (3).

(3) The painting that the infamously successful burglar stole __ from the museum was well guarded.

The fillers read by the filler exposure group were of a comparable length and complexity as the sentences read by the exposure groups, e.g., (2a) and (3).

In both blocks, each sentence was followed by a *yes-no* comprehension question. The number of *yes* and *no* answers was balanced across the exposure block, the targets, and the experiment as a whole. Two experimental lists were created by crossing fronted phrase type (NP-fronting vs. PP-fronting). These lists, in turn, were crossed with exposure type, for a total of six lists.

### 2.1.3 Procedure

Eye movements were recorded using an EyeLink 1000 eye tracker (SR Research: Mississauga, ON, Canada). Participants' heads were stabilized on a chin rest and a forehead rest. Only participants' right eye was tracked at a sampling rate of 1000 Hz. The display allowed a maximum of 120 characters per line in 10 point Monaco font. Stimuli were displayed on a 26 inch monitor, and participants sat 70 cm away from the display.

Before the experiment began, participants received instructions. A 9-point calibration routine was performed at the beginning of the experiment and was monitored throughout with automatic drift checks preceding each trial. Participants' were recalibrated as necessary.

The experiment began with written instructions on the display and five practice items. At the beginning of each trial, a black circle was displayed on the left side of the monitor and was aligned with the beginning of the sentence. The sentence text was displayed after the participant fixated on the circle. After reading the sentence, participants pressed a button on a game controller to remove the sentence from the display and to trigger a *yes-no* comprehension question. These questions were answered by pressing the left (*yes*) or right (*no*) trigger buttons. Comprehension questions never concerned the critical filler-gap dependency portion of the sentence. In total, the experiment lasted approximately 40 minutes.

### 2.1.4 Analysis

Vertical drift in the positions of fixations was hand corrected. Fixations shorter than 80ms were either merged with contiguous fixations within one character or deleted, because readers are unable to extract much information from these very short fixations (Rayner, Pollatsek, Ashby, & Clifton, 2012). Additionally, fixations longer than 800ms were removed, because they usually result from tracker losses or other atypical events.

For purposes of analysis, the target sentences were divided into regions as shown in Table 16.

Table 16. Sample materials and analysis regions for the target sentences in Experiment 3.

| | *1* | *2* | *3* | ***4*** | ***5*** | ***6*** | *7* | *8* |
|---|---|---|---|---|---|---|---|---|
| *NP-fronting* | The suitcase | that | the stealthy, wanted thief | stole | the precious jewels | from | was | full of sentimental items |
| *PP-fronting* | The suitcase | from which | the stealthy, wanted thief | stole | the precious jewels | | was | full of sentimental items |

Four common eye tracking measures were analyzed (Rayner, 1998) – first fixation duration, first pass reading time, regression path time, and percent regressions – in three regions of interest: the verb (region 4), the critical direct object (region 5), and the spillover (region 6 in the NP-fronting condition and region 7 in the PP-fronting condition, i.e., the word following the critical region). First fixation duration is the length of the first fixation on a particular region, no matter the number of words in that region. First pass reading time is the sum of all fixations on the region before exiting the region to the right or to the left. Regression path time is the length of all fixations on the region and any regions earlier in the sentence, and includes time spent rereading previous regions in the sentence. Percent regressions is the percentage of trials in which a regression to a previous region occurred.

Statistical analyses differed between the reading time measures (i.e., first fixation, first pass, and regression path duration) and the percent regressions measure. For the reading time data, each region and measure pair was fit to a linear mixed effect model with exposure group and fronted phrase type as fixed effects and participants and items as random effects (Baayen, Davidson, & Bates, 2008). A logistic mixed effects model was fit for the percent regressions analyses (Jaeger, 2008). Maximum random effects including random slopes were utilized when the models converged (Barr, Levy, Scheepers, & Tily, 2013). These models were run in the R environment (R Core Development Team, 2015) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). *P*-value estimates for the fixed and random effects in the linear models were calculated using the Sattherwaite approximation in the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2015).

For the overall analysis, exposure group compares the two control groups, the filler exposure and DO-gap exposure groups, with the PO-gap exposure group. Further analyses directly compared these control groups. Additional planned pairwise comparisons within exposure group were performed by individually fitting linear or logistic mixed effects models to the data from each group, as appropriate, with fronted phrase type as the fixed effect with random participants and items.

From the exposure block, only the data from the PO-gap exposure group was analyzed. Because there were no PP-fronting sentences in the exposure block, the NP-fronting sentences from the exposure block were compared to the PP-fronting sentences from the experimental block. The same eye tracking measures were analyzed for each of the critical regions shown in Table 16. Models included fronted phrase type as a fixed effect and participants and items as random effects.

## 2.2 Results

### 2.2.1 Experimental block (Block 2)

Comprehension accuracy for the target trials was 95.1%, and trials during which participants answered the comprehension question incorrectly were removed from the analysis, as these trials likely reflect distracted reading.

For each reading time measure (i.e., first fixation, first pass, and regression path duration) and each region, reading times longer than three standard deviations greater than the mean were excluded. This resulted in 1.7% of the data being excluded. Table 17 presents the participant means on each measure for each region of analysis as well as the standard errors of the participant means; Figure 11 presents the same data in graphical form. In the verb region, there were no significant main effects or interactions on any of the eye tracking measures (all $p$s $> 0.1$). There were also no significant differences between the control groups (all $p$s $> 0.1$) in this region. In the critical filled gap region, there were significant effects in both regression path time and percent regressions. There was a significant main effect of fronting type ($p < 0.05$) on regression path times, which is indicative of the filled gap effect; regression path times were longer in the NP-fronting condition when a direct object gap is possible and predicted. Additionally, there was a significant interaction of exposure group and fronting type ($p < 0.05$). Table 18 presents a summary of the statistical analysis.

Table 17. Experiment 3 participant mean reading times in milliseconds (standard error) and percent regressions.

| Measure | *Verb Region* | *Filled Gap Region* | *Spillover Region* |
|---|---|---|---|
| **First fixation duration** | | | |
| Filler exposure, NP-fronting | 234 (5) | 223 (5) | 231 (7) |
| Filler exposure, PP-fronting | 230 (5) | 224 (6) | 219 (6) |
| DO-gap exposure, NP-fronting | 235 (4) | 237 (5) | 221 (6) |
| DO-gap exposure, PP-fronting | 243 (5) | 233 (3) | 231 (5) |
| PO-gap exposure, NP-fronting | 241 (5) | 229 (5) | 224 (7) |
| PO-gap exposure, PP-fronting | 242 (5) | 224 (4) | 215 (5) |
| **First pass time** | | | |
| Filler exposure, NP-fronting | 274 (7) | 539 (21) | 247 (9) |
| Filler exposure, PP-fronting | 267 (7) | 491 (18) | 239 (7) |
| DO-gap exposure, NP-fronting | 262 (6) | 486 (16) | 239 (6) |
| DO-gap exposure, PP-fronting | 273 (7) | 486 (14) | 249 (6) |
| PO-gap exposure, NP-fronting | 267 (8) | 470 (15) | 243 (9) |
| PO-gap exposure, PP-fronting | 270 (8) | 444 (13) | 246 (9) |
| **Regression path time** | | | |
| Filler exposure, NP-fronting | 305 (8) | 747 (30) | 315 (17) |
| Filler exposure, PP-fronting | 327 (15) | 625 (25) | 324 (20) |
| DO-gap exposure, NP-fronting | 291 (8) | 686 (27) | 346 (28) |
| DO-gap exposure, PP-fronting | 299 (8) | 610 (29) | 562 (45) |
| PO-gap exposure, NP-fronting | 303 (11) | 680 (30) | 320 (22) |
| PO-gap exposure, PP-fronting | 306 (10) | 665 (35) | 381 (31) |
| **Percent regressions** | | | |
| Filler exposure, NP-fronting | 8.2 (1.3) | 26.0 (2.3) | 13.3 (2.9) |
| Filler exposure, PP-fronting | 10.7 (2.0) | 14.7 (1.6) | 14.5 (2.0) |
| DO-gap exposure, NP-fronting | 9.8 (1.3) | 28.2 (3.1) | 17.5 (3.2) |
| DO-gap exposure, PP-fronting | 9.7 (1.7) | 15.6 (1.6) | 35.7 (3.3) |
| PO-gap exposure, NP-fronting | 9.0 (1.3) | 25.6 (2.9) | 16.8 (2.4) |
| PO-gap exposure, PP-fronting | 10.0 (1.9) | 25.9 (2.4) | 22.9 (3.4) |

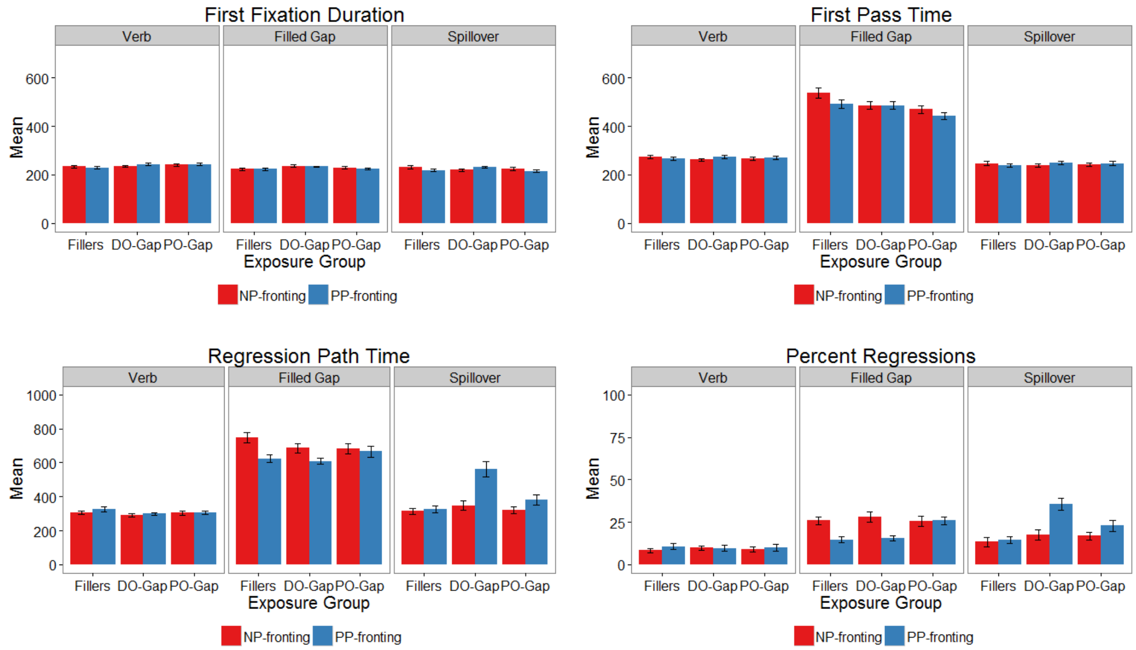



Figure 11. Participant mean reading times in milliseconds and percent regressions by region, exposure group, and fronting type for Experiment 3. Error bars represent ±1 standard error.

In the verb region, there were no significant main effects or interactions on any of the eye tracking measures (all *p*s > 0.1). There were also no significant differences between the control groups (all *p*s > 0.1) in this region. In the critical filled gap region, there were significant effects in both regression path time and percent regressions. There was a significant main effect of fronting type ($p < 0.05$) on regression path times, which is indicative of the filled gap effect; regression path times were longer in the NP-fronting condition when a direct object gap is possible and predicted. Additionally, there was a significant interaction of exposure group and fronting type ($p < 0.05$).

Table 18. Summary of model estimates, standard errors, and *t*-values (for linear mixed effect models) and *Z*-values (for logit mixed effect models) for the overall model of eye movement measures in Experiment 3.

| | *Verb Region* | | | *Filled Gap Region* | | | *Spillover Region* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Measure* | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) |
| **First fixation duration** | | | | | | | | | |
| Intercept | 238.57 | 4.91 | 48.58*** | 227.65 | 4.52 | 50.36*** | 221.98 | 5.93 | 37.42*** |
| Exposure Group | 6.37 | 9.25 | 0.69 | -2.53 | 8.94 | -0.28 | -1.43 | 10.52 | -0.14 |
| Fronting Type | -4.29 | 5.75 | -0.75 | 3.81 | 4.23 | 0.90 | 4.16 | 6.31 | 0.66 |
| Exposure x Fronting | 0.85 | 10.52 | 0.08 | 3.32 | 7.97 | 0.42 | 2.81 | 12.30 | 0.23 |
| **First pass time** | | | | | | | | | |
| Intercept | 268.17 | 7.98 | 33.59*** | 479.29 | 19.75 | 24.27*** | 247.20 | 8.30 | 29.79*** |
| Exposure Group | 1.00 | 13.40 | 0.08 | -42.68 | 33.73 | -1.27 | 8.97 | 15.80 | 0.57 |
| Fronting Type | -3.73 | 7.10 | -0.53 | 24.12 | 15.06 | 1.60 | 5.33 | 9.10 | 0.59 |
| Exposure x Fronting | -2.04 | 14.46 | -0.14 | 2.25 | 27.92 | 0.08 | -0.12 | 17.93 | -0.01 |
| **Regression path time** | | | | | | | | | |
| Intercept | 303.28 | 11.49 | 26.39*** | 669.30 | 33.87 | 19.76*** | 360.74 | 24.71 | 14.60*** |
| Exposure Group | 6.10 | 19.10 | 0.32 | 2.69 | 57.14 | 0.05 | -7.96 | 46.27 | -0.17 |
| Fronting Type | -1.46 | 12.44 | -0.12 | 59.97 | 22.49 | 2.67* | -56.31 | 49.07 | -1.15 |
| Exposure x Fronting | 9.66 | 26.60 | 0.36 | -78.73 | 39.97 | -1.97* | 44.70 | 89.59 | 0.50 |
| **Percent regressions** | | | | | | | | | |
| Intercept | -2.58 | 0.21 | -12.28*** | -1.39 | 0.15 | -9.41*** | -1.81 | 0.21 | -8.65*** |
| Exposure Group | 0.05 | 0.32 | 0.16 | 0.32 | 0.28 | 1.15 | 0.06 | 0.32 | 0.17 |
| Fronting Type | 0.32 | 0.31 | 1.02 | 0.42 | 0.15 | 2.91** | -0.12 | 0.34 | -0.36 |
| Exposure x Fronting | 0.07 | 0.50 | 0.14 | -0.81 | 0.29 | -2.79** | 0.45 | 0.51 | 0.88 |

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

To explore this interaction, an additional linear mixed effect model directly compared the filler exposure group with the DO-gap exposure group. In this model, there was a main effect of fronting type ($\beta = 122.15$, $t = 3.39$, $p < 0.01$) and no other significant differences. This indicates that both control groups demonstrated the filled gap effect and did not differ from one another. This is further supported by pairwise comparisons; regression path times in the filled gap region were longer when the NP was fronted for both the filler exposure ($\beta = 124.07$, $t = 3.55$, $p < 0.01$) and DO-gap exposure groups ($\beta = 75.08$, $t = 2.11$, $p < 0.05$). However, the filled gap effect was not demonstrated by the PO-gap exposure group; there was no difference between the two fronting types for this group ($\beta = 19.58$, $t = 0.55$, $p > 0.1$).

For percent regressions in the filled gap region, the filled gap effect is demonstrated by the significant main effect of fronting type ($p < 0.01$). There was also a significant interaction of exposure group and fronting type ($p < 0.01$). An additional logit mixed effect model directly compared the control groups and found a significant main effect of fronting type ($\beta = 0.66$, $Z = 2.44$, $p < 0.05$) and no other significant effects. As with the regression path times in this region, this effect indicates that both control groups demonstrated the filled gap effect and did not differ from one another, which was supported by the pairwise comparisons within exposure group. There were significantly more trials with regressions for the NP-fronting condition than the PP-fronting condition for the filler exposure group ($\beta = 0.65$, $t = 2.11$, $p < 0.05$), and this effect was marginal for the DO-gap exposure group ($\beta = 0.60$, $t = 1.86$, $p = 0.06$). In contrast, there was no significant difference in percent regressions based on fronting type for the PO-gap exposure group ($\beta = -0.12$, $t = -0.42$, $p > 0.1$). These differences between the control groups and the PO-gap exposure group suggest that active gap filling was diminished after concentrated exposure to PO-gaps.

### 2.2.2 Exposure block (Block 1)

The results from the experimental block suggest that the PO-gap exposure group ceased actively associating the filler with the verb, while the filler exposure group and the DO-gap exposure group continued to demonstrate active gap filling. This conclusion, however, rests on the fact that the group exposed to PO-gaps actively associated the filler with the verb before exposure. This can be tested by comparing the NP-fronting, PO-gap sentences in the exposure block (Block 1) to the PP-fronting sentences in the experimental block (Block 2). Table 19 presents the data relevant for this analysis from the PO-gap exposure group, and Table 20 summarizes the analysis.

Table 19. PO-gap exposure group participant mean reading times in milliseconds (standard error) and percent regressions.

| Measure | *Verb Region* | *Filled Gap Region* | *Spillover Region* |
|---|---|---|---|
| **First fixation duration** | | | |
| NP-fronting, Block 1 | 238 (8) | 229 (6) | 215 (7) |
| PP-fronting, Block 2 | 242 (5) | 224 (4) | 215 (5) |
| **First pass time** | | | |
| NP-fronting, Block 1 | 286 (15) | 497 (21) | 247 (11) |
| PP-fronting, Block 2 | 270 (8) | 444 (13) | 246 (9) |
| **Regression path time** | | | |
| NP fronting, Block 1 | 323 (23) | 721 (50) | 287 (18) |
| PP-fronting, Block 2 | 306 (10) | 665 (35) | 381 (31) |
| **Percent regressions** | | | |
| NP fronting, Block 1 | 8.6 (2.1) | 29.2 (4.5) | 9.5 (1.8) |
| PP-fronting, Block 2 | 10.0 (1.9) | 25.9 (2.4) | 22.9 (3.4) |

Table 20. Summary of model estimates, standard errors, and *t*-values (for linear mixed effect models) and *Z*-values (for logit mixed effect models) for the exposure block analysis.

| | *Verb Region* | | | *Filled Gap Region* | | | *Spillover Region* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Measure* | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) |
| **First fixation duration** | | | | | | | | | |
| Intercept | 240.26 | 7.56 | 31.79*** | 226.70 | 6.13 | 37.0*** | 217.75 | 6.96 | 31.28*** |
| Fronting Type | -6.26 | 10.39 | -0.60 | 4.71 | 7.68 | 0.61 | -3.73 | 8.99 | -0.41 |
| **First pass time** | | | | | | | | | |
| Intercept | 277.24 | 14.05 | 19.73*** | 471.45 | 22.37 | 21.07*** | 250.79 | 12.46 | 20.13*** |
| Fronting Type | 12.12 | 12.72 | 0.95 | 52.80 | 19.62 | 2.69** | -0.69 | 13.64 | -0.5 |
| **Regression path time** | | | | | | | | | |
| Intercept | 314.08 | 20.03 | 15.68*** | 692.56 | 53.66 | 12.91*** | 329.42 | 34.63 | 9.51*** |
| Fronting Type | 18.07 | 18.89 | 0.96 | 62.14 | 46.72 | 1.33 | -70.38 | 65.10 | -1.08 |
| **Percent regressions** | | | | | | | | | |
| Intercept | -2.71 | 0.34 | 08.07*** | -1.15 | 0.23 | -4.99*** | -1.93 | 0.25 | -7.90*** |
| Fronting Type | 0.22 | 0.59 | 0.71 | 0.12 | 0.22 | 0.55 | -0.80 | 0.38 | -2.09* |

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

The expected filled-gap effect was observed. In the verb region, there were no significant differences in any of the eye tracking measures: first fixation duration ($\beta$ = -6.26, $t$ = -0.60, $p > 0.1$), first pass time ($\beta$ = 12.12, $t$ = 0.95, $p > 0.1$), regression path time ($\beta$ = 18.07, $t$ = 0.96, $p > 0.1$), and percent regressions ($\beta$ = 0.22, $Z$ = 0.38, $p > 0.1$). In the filled gap region, first pass time was significantly longer in the NP-fronting condition compared to the PP-fronting condition ($\beta$ = 52.80, $t$ = 2.69, $p < 0.01$), but there were no significant effects in first fixation duration ($\beta$ = 4.71, $t$ = 0.61, $p > 0.1$), regression path time ($\beta$ = 62.14, $t$ = 1.33, $p > 0.1$), or percent regressions ($\beta$ = 0.12, $Z$ = 0.22, $p > 0.1$). Finally, in the spillover region, there were significantly greater regressions in the NP-fronting condition ($\beta$ = -0.80, $Z$ = -2.09, $p < 0.05$) with no significant differences in first fixation duration ($\beta$ = -3.73, $t$ = -0.41, $p > 0.1$), first pass time ($\beta$ = -0.69, $t$ = -0.05, $p >$ 0.1), or regression path time ($\beta$ = -70.38, $t$ = -1.08, $p > 0.1$). No strong conclusions can be drawn from significant effects in the spillover region, however, because this region consisted of a different word based on the condition.

## 2.3 Discussion

Experiment 3 utilized the blocked adaptation paradigm of Fine et al. (2013) to examine whether filler-gap dependency processing can be affected by the distribution of gaps in the input. For the control groups, exposure to fillers and DO-gaps did not affect active gap filling; regression path times and percent regressions on the critical filled gap region were significantly greater for NP-fronting sentences than for PP-fronting sentences. For the PO-gap exposure group, however, there was no difference between the two types of sentences, which indicates that the PO-gap exposure group was not actively associating the filler with the verb during the second, experimental block. This difference cannot be attributed to an inherent difference in active gap filling between the groups; participants in this group had more regressions and longer regression paths in the NP-fronting, PO-gap sentences from the exposure block compared to the PP-fronting condition from the experimental block. Initially, they were actively associating the filler with the verb and were surprised by the presence of a direct object NP.

Taken together, these results suggest that syntactic adaptation effects extend outside the realm of ambiguity resolution to filler-gap dependency processing. Additionally, they provide evidence that probabilistic information from the input can override memory biases that favor shorter dependencies, at least in this case. The fact that structural probabilities derived from the input statistics can affect gap predictions provides evidence for the probabilistic account of active gap filling. These results demonstrated that participants' active gap filling behavior reflected the distribution of direct object gaps in their input, but it did not demonstrate whether their syntactic predictions reflected the distribution of prepositional object gaps. Experiment 4 examines whether adults were generating prepositional object gap predictions in addition to minimizing their direct object gap predictions.

## 3 Experiment 4 – Blocked adaptation: filled prepositional object gap

The original Fine et al. (2013) experiment consisted of three blocks, and the third block demonstrated that not only did the reduced relatives become easier to process, but that adaptation reversed the direction of processing difficulty; main verbs became more difficult to process. The results of Experiment 3 demonstrated that the PO-gap exposure group did not predict a direct object gap, but they did not indicate whether or not they were actively predicting a prepositional object gap instead. It is possible, therefore, that participants inhibited syntactic predictions in general rather than inhibiting direct object gap predictions specifically.

Also, probabilistic parsing accounts predict that parsing decisions should reflect the statistics derived from the input. As the input distribution both favors prepositional object gaps and disfavors direct object gaps, the shift from direct object gap predictions to prepositional object gap predictions would provide stronger evidence for the probabilistic parsing account. Experiment 4 replaces the experimental block from Experiment 3 with novel stimuli that examine whether or not a prepositional object gap is being actively predicted. Prepositional object gap predictions were evaluated using sentences with filled prepositional object gaps (*The suitcase that the thief stole from the hotel contained precious jewels*). Were a prepositional object gap predicted, participants should not be expecting a complement NP in the prepositional phrase (*from the hotel*) and should slowdown when reading the complement of the preposition (*the hotel*).

## 3.1 Method

### 3.1.1 Participants

Sixty native English speaking Johns Hopkins undergraduates participated for course credit.

### 3.1.2 Design and Materials

The design of Experiment 4 shares many features with Experiment 3. As in Experiment 3, there is a between-participant variable of exposure group. Also, the exposure block is identical to that from Experiment 3 (see Table 21).

Table 21. Design of Experiment 4.

<table>
<tr><th>Group</th><th>Block 1 (Exposure)</th><th>Block 2 (Experimental)</th></tr>
<tr><td>PO-gap exposure</td><td>24 NP-fronting filled object gap sentences (2a)</td><td rowspan="3">24 target pairs (4) + 48 fillers</td></tr>
<tr><td>DO-gap exposure</td><td>24 direct object gap sentences (3)</td></tr>
<tr><td>Filler exposure</td><td>24 fillers</td></tr>
</table>

The target sentences for the experimental block were novel filled prepositional object gap sentences (4a). These sentences consist of filler-gap dependencies with a direct object gap followed by a full prepositional phrase.

(4) a. *Non-island:* The suitcase that the stealthy, wanted thief stole __ from the hotel room contained precious jewels.
   b. *Island:* The suitcase that the stealthy, wanted thief **who** stole from the hotel room coveted __ contained precious jewels.

The filled prepositional object gap sentences were compared to sentences in which the first verb (e.g., *stole*) and the critical PP were enclosed within a relative clause island (4b). Islands are a grammatical constraint that prevents dependency formation (Chomsky, 1973, 1977; Ross, 1967), and the parser has been shown to respect them during online processing of filler-gap dependencies (Omaki & Schulz, 2011; Stowe, 1986; Traxler & Pickering, 1996). A gap cannot grammatically be located within an island, so the parser does not attempt to actively fill the gap at the relative clause verb. Given this respect for the island constraint, a prepositional object gap should not be predicted in the island condition. If the parser actively predicts a prepositional object gap, a *filled gap effect* is expected on the complement of the preposition: a reading time slowdown on the underlined region in the non-island condition (4a) compared to the island condition (4b).

As in Experiment 3, each sentence was followed by a *yes-no* comprehension question, and the number of *yes* and *no* answers was balanced. Two experimental lists were created by crossing island status (non-island vs. island). These lists, in turn, were crossed with exposure type, for a total of six lists.

### 3.1.3 Procedure

The procedure for Experiment 4 was identical to that of Experiment 3.

### 3.1.4 Analysis

The analysis procedure for Experiment 4 was identical to that of Experiment 3 with different regions of interest, see Table 22.

Table 22. Sample materials and analysis regions for the target sentences in Experiment 4.

| | *1* | *2* | *3* | *4* | *5* | ***6*** | *7* | ***8*** | *9* |
|---|---|---|---|---|---|---|---|---|---|
| *Non-island* | The suitcase | that | the stealthy, wanted thief | | stole | from | the hotel room | contained | precious jewels |
| *Island* | The suitcase | that | the stealthy, wanted thief | who | stole | from | the hotel room | coveted | contained precious jewels |

For the target sentences in (4), the three regions of interest are the preposition (region 6), the critical prepositional object (region 7), and the spillover region (region 8, i.e., the following verb).

## 3.2 Results

Comprehension accuracy for the target trials was 91%, and trials during which participants answered the comprehension question incorrectly were removed from the analysis as these trials likely reflect distracted reading.

For each reading time measure (i.e., first fixation, first pass, and regression path duration) and each region, reading times longer than three standard deviations greater than the mean were excluded. This resulted in 1.7% of the data being excluded. Table 23 presents the participant means on each measure for each region of analysis as well as the standard errors of the participant means; Figure 12 presents the same data in graphical form.

In the preposition region, there was a marginal effect of exposure group on first fixation duration ($p < 0.1$), which was probably a spurious effect as there were no other significant effects (all other *p*s > 0.1). Comparing the control groups, there was a significant interaction of control group and islandhood on first fixation duration ($\beta = -30.57$, $t = -2.19$, $p < 0.05$). This is also likely a spurious effect as there were no other significant effects in this region (all *p*s > 0.1). Table 24 presents a summary of the statistical analysis.

Table 23. Experiment 4 participant mean reading times in milliseconds (standard error) and percent regressions.

| Measure | *Preposition Region* | *Filled PO-Gap Region* | *Spillover Region* |
|---|---|---|---|
| **First fixation duration** | | | |
| Filler exposure, Non-island | 194 (6) | 215 (4) | 213 (5) |
| Filler exposure, Island | 215 (7) | 219 (4) | 228 (5) |
| DO-gap exposure, Non-island | 209 (6) | 205 (4) | 227 (6) |
| DO-gap exposure, Island | 206 (6) | 215 (4) | 234 (4) |
| PO-gap exposure, Non-island | 218 (6) | 221 (4) | 229 (5) |
| PO-gap exposure, Island | 233 (6) | 223 (4) | 233 (4) |
| **First pass time** | | | |
| Filler exposure, Non-island | 208 (7) | 486 (19) | 257 (6) |
| Filler exposure, Island | 230 (9) | 432 (13) | 282 (8) |
| DO-gap exposure, Non-island | 219 (7) | 458 (16) | 293 (9) |
| DO-gap exposure, Island | 213 (6) | 431 (16) | 288 (7) |
| PO-gap exposure, Non-island | 229 (7) | 446 (13) | 281 (8) |
| PO-gap exposure, Island | 241 (7) | 434 (13) | 294 (7) |
| **Regression path time** | | | |
| Filler exposure, Non-island | 245 (7) | 641 (20) | 411 (24) |
| Filler exposure, Island | 267 (11) | 651 (24) | 334 (12) |
| DO-gap exposure, Non-island | 263 (8) | 638 (26) | 435 (25) |
| DO-gap exposure, Island | 274 (13) | 667 (30) | 364 (14) |
| PO-gap exposure, Non-island | 265 (10) | 695 (24) | 358 (16) |
| PO-gap exposure, Island | 285 (10) | 698 (19) | 375 (15) |
| **Percent regressions** | | | |
| Filler exposure, Non-island | 11.4 (2.2) | 20.6 (2.4) | 28.2 (2.6) |
| Filler exposure, Island | 13.6 (2.0) | 28.3 (2.4) | 10.5 (1.8) |
| DO-gap exposure, Non-island | 19.1 (2.5) | 21.8 (2.8) | 18.4 (2.0) |
| DO-gap exposure, Island | 21.0 (2.4) | 26.2 (2.8) | 9.4 (1.5) |
| PO-gap exposure, Non-island | 13.1 (2.5) | 32.3 (3.0) | 13.8 (2.4) |
| PO-gap exposure, Island | 16.7 (2.6) | 34.2 (2.4) | 16.5 (1.6) |

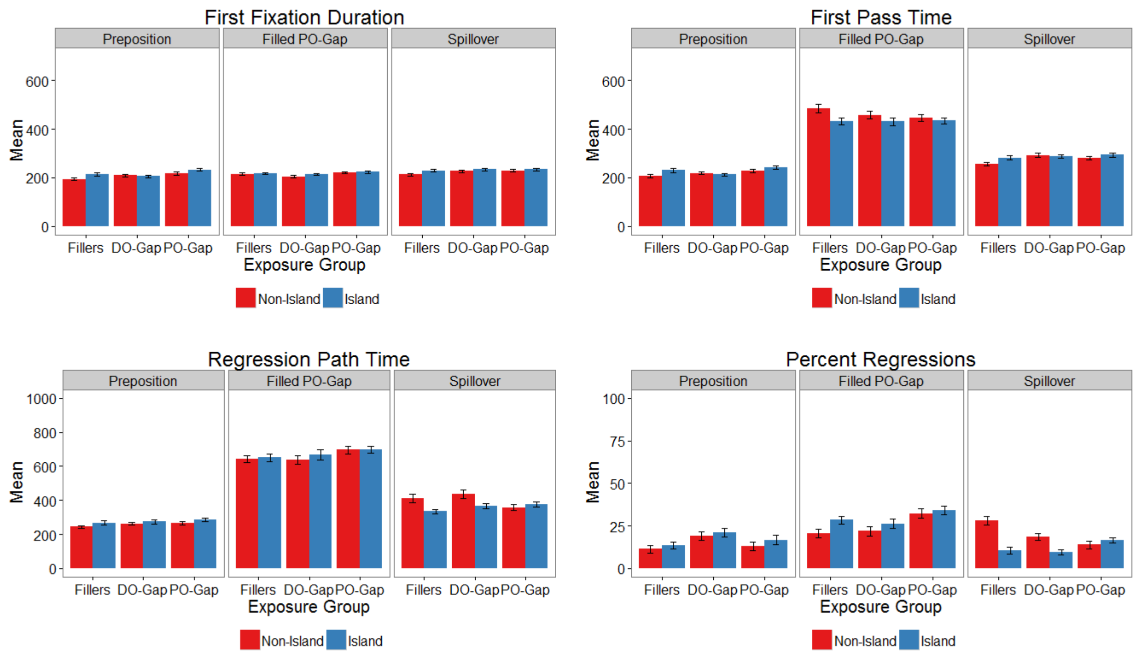



Figure 12. Participant mean reading times in milliseconds and percent regressions by region, exposure group, and fronting type for Experiment 4. Error bars represent ±1 standard error.

In the critical filled prepositional object gap region, there were only significant effects on percent regressions (all other *p*s > 0.1). There was a main effect of exposure group ($p < 0.05$), such that the control groups (fillers and DO-gaps) had significantly less regressions from that region than the PO-gap exposure group. Also, there was a marginal effect of island status ($p < 0.1$); there were less regressions from the prepositional object region in the non-island conditions than in the island conditions. This reflects the fact that islands are relatively difficult to process. Comparing the control groups, there was a significant main effect of islandhood on first pass time ($\beta = -40.40$, $t = -2.34$, $p < 0.05$). This effect is in the expected direction of the filled prepositional object gap effect, but it occurs in the control groups rather than in the group exposed to PO-gaps. Since the filler could be actively associated with the verb in these sentences, it is unclear what the source of this slowdown is for groups not exposed to PO-gaps.

Table 24. Summary of model estimates, standard errors, and *t*-values (for linear mixed effect models) and *Z*-values (for logit mixed effect models) for the overall model of eye movement measures in Experiment 4.

| | *Preposition Region* | | | *Filled PO-Gap Region* | | | *Spillover Region* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Measure* | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) |
| **First fixation duration** | | | | | | | | | |
| Intercept | 214.97 | 5.46 | 39.36*** | 218.15 | 4.14 | 52.64*** | 226.25 | 4.78 | 47.37*** |
| Exposure Group | 20.55 | 10.56 | 1.95† | 9.09 | 7.45 | 1.22 | 6.88 | 8.19 | 0.84 |
| Island Status | 13.45 | 8.17 | 1.65 | 4.50 | 4.16 | 1.08 | 11.66 | 7.09 | 1.65 |
| Exposure x Island | 8.68 | 15.23 | 0.57 | -4.06 | 8.08 | -0.50 | -11.06 | 12.03 | -0.92 |
| **First pass time** | | | | | | | | | |
| Intercept | 226.67 | 6.28 | 36.08*** | 447.69 | 19.37 | 23.11*** | 269.45 | 12.46 | 21.63*** |
| Exposure Group | 18.74 | 11.60 | 1.62 | -13.17 | 28.08 | -0.47 | 6.48 | 11.45 | 0.57 |
| Island Status | 12.03 | 10.50 | 1.15 | -25.80 | 16.19 | -1.59 | 33.53 | 18.81 | 1.78† |
| Exposure x Island | 11.72 | 20.82 | 0.56 | 28.73 | 33.74 | 0.85 | -4.57 | 19.73 | -0.23 |
| **Regression path time** | | | | | | | | | |
| Intercept | 271.36 | 8.32 | 32.64*** | 674.18 | 29.73 | 22.68*** | 341.45 | 27.48 | 12.43*** |
| Exposure Group | 22.91 | 15.46 | 1.48 | 47.61 | 45.13 | 1.06 | -8.09 | 25.66 | -0.32 |
| Island Status | 22.53 | 13.29 | 1.70 | 8.62 | 31.46 | 0.27 | 32.39 | 50.58 | 0.64 |
| Exposure x Fronting | 23.20 | 28.61 | 0.81 | -17.03 | 50.98 | -0.33 | 52.75 | 46.60 | 1.13 |
| **Percent regressions** | | | | | | | | | |
| Intercept | -1.69 | 0.14 | -12.23*** | -1.10 | 0.16 | -7.04*** | -2.02 | 0.20 | -10.28*** |
| Exposure Group | -0.02 | 0.25 | -0.09 | 0.54 | 0.26 | 2.05* | -0.08 | 0.27 | -0.29 |
| Island Status | 0.32 | 0.25 | 1.27 | 0.31 | 0.17 | 1.81† | -0.39 | 0.25 | -1.57 |
| Exposure x Island | 0.31 | 0.51 | 0.61 | -0.34 | 0.34 | -1.00 | 1.34 | 0.46 | 2.91** |

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$

In the spillover region, there were also only effects on percent regressions (all other *p*s > 0.1); there was a significant interaction of exposure group and island status ($p < 0.01$). A linear mixed effect model directly comparing the two control groups revealed a main effect of island status ($\beta = -1.14$, $Z = -3.62$, $p < 0.001$). This effect is not consistent, however, as pairwise comparisons revealed a significant effect of island status only for the filler exposure group ($\beta$ = -1.23, $Z$ = -2.13, $p < 0.05$), and not for the other exposure groups (DO-gap exposure: $\beta$ = -0.74, $Z$ = -1.08, $p > 0.1$; PO-gap exposure: $\beta$ = 0.84, $Z$ = 1.25, $p > 0.1$). Additionally, this effect was in the opposite direction of the effect in the critical region – more regressions originated from the spillover region of the non-island conditions – and affected a group that was not supposed to have been influenced by adaptation effects.

### 3.3 Discussion

Experiment 4 used a novel filled prepositional object gap sentence design to assess whether the diminished direct object gap predictions in Experiment 3 were accompanied by increased prepositional object gap predictions. The results of this study suggest that this is not the case. The only significant interaction was found in the spillover region on percent regressions, but this suggests that the control groups may have been demonstrating a filled prepositional object effect not the PO-gap exposure group.

The results of Experiment 3 could be attributed to a general diminishing of gap prediction rather than a shift from one specific prediction to another (i.e., from direct object gaps to prepositional object gaps). The probabilistic parsing account predicts that processing should directly reflect the structural distribution; any increase in expectation of one structure should be accompanied by a decrease in expectation of a competing structure (and vice versa). For example, the main clause and reduced relative continuations studied in Fine et al. (2013) were in direct competition. Thus, decreasing the probability of one structure automatically increased the probability of the other. This was reflected in the fact that processing difficulty on the disambiguating region increased for main clause continuations and decreased for reduced relative continuations. In Experiments 3 and 4, a shift in probability from direct object gaps to prepositional object gaps was not observed. Rather, exposure to an unexpected gap position only had an effect on the default direct object gap predictions. This suggests that exposure to PO-gaps may have decreased participants confidence in their gap predictions to the point where they ceased predicting a gap position in general.

This finding is also initial evidence that the role of language experience on predictive structure building, or at least gap predictions in filler-gap dependency processing, may be fundamentally different from predictive structure selection. Language experience did not have the same effect on predictive structure building processes, i.e., gap predictions in filler-gap dependency processing in Experiments 3 and 4, as it did on predictive structure selection processes, i.e., argument structure ambiguities like the main verb / reduced relative ambiguity (Fine et al., 2013). Both of these ideas are discussed in greater detail in Chapter 5.

While these findings could have serious implications for the effect of language experience on filler-gap dependency processing, Experiment 4 does have a significant limitation. Because the target filled prepositional object gap sentences in Experiment 4 replaced the target filled object gap sentences from Experiment 3, there is no way to establish that participants in the Experiment 4 PO-gap exposure group were attenuating their direct object gap predictions, nor is it possible to demonstrate that they were generating these direct object gap predictions in the first place. Thus, an alternative explanation for the lack of prepositional object gap predictions in this experiment is that direct object gap predictions were not diminished by exposure to prepositional object gaps, so participants actively associated the filler with the optionally transitive verb. The current design of Experiment 4 has no way of ruling out this alternative. Future work is needed to test for diminishing direct object gap predictions and rising prepositional object gap predictions within the same experiment.

# 4 Experiment 5 – Adaptation with masked input

Despite the findings from Experiment 3 that probabilistic information can affect gap predictions, it is unclear whether the adaptation of syntactic predictions generalizes outside the laboratory and into naturalistic language processing. The skewed distribution of PO-gaps in the blocked design of Experiments 3 and 4 may lead participants to develop task-specific expectations about upcoming input. In other words, the input was presented in a context (i.e., as part of a sentence processing experiment) where participants may expect manipulations of this sort. These experimental factors suggest that the results from Experiment 3 and those from other syntactic adaptation studies (e.g., Fine et al., 2013) may not reflect an effect of language experience on online processing strategies. Rather, they may indicate an effect of distributional information on the likelihood of task-specific strategies. Exposure to less probable input may lead participants to generate more task-specific parsing strategies because the experimental environment does not reflect the distribution of structures outside the laboratory. Experiment 5 examines whether gap distributions are generalized across experiments by masking the exposure block as a separate study and testing for a plausibility mismatch effect. Additionally, the critical input sentences are presented within a story, which is a naturalistic learning environment for adults.

## 4.1 Methods

### 4.1.1 Participants

Forty-seven native English speaking Johns Hopkins University undergraduates participated for course credit.

### 4.1.2 Design

Experiment 5 was presented to participants as two unrelated studies. The first study was a sentence recognition experiment, which served as the exposure phase, comparable to the first block in Experiments 3 and 4, and masked the presentation of the skewed input. The second study was an eye tracking study utilizing the plausibility mismatch effect to examine participants' gap predictions after exposure.

### 4.1.3 Materials

#### *4.1.3.1 Part 1: Sentence recognition*

The materials for the sentence recognition study consist of twelve short stories. The stories contained the sentences that manipulated the input distribution of gap positions. Participants were divided into two groups: a prepositional object (PO) gap exposure group and a direct object (DO) gap exposure group. Each story contained 4 critical sentences, for a total of 48 input filler-gap dependencies. An example PO-gap story is presented in (5); the critical filled gap sentences are bolded.

(5) Jill and Justin planned to spend a day exploring New York City. Over the past few weeks, they had been reading all the information they could find about things to do there. **The newspaper article that their friend wrote the blog post about __ gave great tips about the most popular attractions in the city.** They decided that they definitely wanted to go shopping in Times Square and that, in the evening, they would see a Broadway play. They left on the train the next morning. After they arrived in New York, they made their way to Times Square. **The shops that they encountered the crowds in __ were enormous.** They looked around for a while, but decided not to buy anything so that they would not have to carry bags with them the rest of the day. After all of their time in the crowds, Jill and Justin were

exhausted and they decided to find a place where they could eat lunch. **The deli's menu that Jill discovered the delicious sandwich on __ was much more expensive than she expected.** The couple decided to splurge, though, since it was their first time in the city. Then, they walked through Central Park until it was time for them to take their seats for the show. **The musical that the couple watched the famous actress in __ made them want to come back and see a Broadway performance again.** Jill and Justin were sad to leave after such an exciting day.

The direct object gap versions of these critical sentences are given in (6). They were created by simply fronting the direct object from the critical PO-gap sentences rather than the prepositional object.

(6) a. The blog post that their friend wrote __ about the newspaper article gave great tips about the most popular attractions in the city.
b. The crowds that they encountered __ in the shops were enormous.
c. The delicious sandwich that Jill discovered __ on the deli's menu was much more expensive than she expected.
d. The famous actress that the couple watched __ in the musical made them want to come back and see a Broadway performance again.

The stories were paired with sentences either duplicating ones from the story (7a) or slightly altered (7b). None of these sentences involved the critical direct object or prepositional object gap sentences. The participants' task was to identify whether these sentences appeared in the story that they just read. Each story was paired with two sentences for a total of 24 sentence recognition trials.

(7) a. Jill and Justin were sad to leave after such a tiring day in the city.
b. Jill and Justin were <u>happy</u> to leave after such a tiring day in the city.

#### *4.1.3.2 Part 2: Eye tracking*

The second study was an eye tracking experiment, similar to the second block in both Experiments 3 and 4. Unlike the previous adaptation experiments, active gap filling is tested using the plausibility mismatch effect (Traxler & Pickering, 1996). The target sentences included fillers that are plausible direct objects of the verb, e.g., *wrote* and *the book* (8a), or that are implausible objects, e.g., *wrote* and *the city* (8b).

(8) a. *Plausibility Match:* The book that the author wrote thoughtfully about __ was named for an explorer.
b. *Plausibility Mismatch:* The city that the author wrote thoughtfully about __ was named for an explorer.

Participants in both exposure groups read 16 target sentences and 48 fillers; each was followed by a *yes-no* comprehension question. If the parser is actively predicting a direct object gap, there should be a reading time slowdown on the verb in the plausibility mismatch condition because a direct object gap interpretation is impossible.

For the eye tracking portion, two experimental lists were generated by crossing plausibility. These lists were also crossed with exposure group (PO-gaps vs. DO-gaps) for a total of four lists. If the input distribution of gap positions transfers from the sentence recognition experiment to the eye tracking experiment, the results should be similar to Experiment 3; the group exposed to PO-gaps should not demonstrate the plausibility mismatch effect because their active association of the filler with the verb is weakened. Thus, they should not be surprised when the filler is not a plausible direct object of the verb. Alternatively, participants may treat input distributions as local and thus only apply them within an experiment. Were this the case, the PO-gap exposure group should not differ from the DO-gap exposure group. Both groups should actively predict a direct object gap and should, therefore, have slower reading times in the plausibility mismatch conditions.

### 4.1.4 Procedure

#### *4.1.4.1 Part 1: Sentence recognition*

This portion of the experiment was presented using the Ibex online experiment platform (Drummond, 2010), which allows the stories and sentences to be displayed on a browser. Participants were instructed to read the stories aloud. After the story, a sentence was displayed on the screen, and participants were asked to identify two sentences as novel or duplicates from the story.

#### *4.1.4.2 Part 2: Eye tracking*

The eye tracking procedure was identical to that from Experiments 3 and 4.

### 4.1.5 Analysis

#### *4.1.5.1 Part 1: Sentence recognition*

Because the underlying purpose of the sentence recognition task was to present skewed information on gap positions, it is important to analyze accuracy on this task to make sure that participants were paying attention. Accuracy in recognizing sentences was analyzed using a logit mixed effect model (Jaeger, 2008) with story exposure group as the fixed effect and random intercepts for participants and items (i.e., stories).

#### *4.1.5.2 Part 2: Eye tracking*

The analysis procedure for the eye tracking portion of the study was identical to that for Experiments 3 and 4 with different regions of analysis, see Table 25.

Table 25. Sample materials and analysis regions for the target sentences in Experiment 5.

| | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* |
|---|---|---|---|---|---|---|---|---|
| *Plausibility match* | The book | that | **the author** | **wrote** | **thoughtfully** | about | was | named for an explorer |
| *Plausibility mismatch* | The city | that | **the author** | **wrote** | **thoughtfully** | about | was | named for an explorer |

Unlike filled gap sentences, the verb is the critical region for the plausibility mismatch effect; whether or not the filler is a plausible direct object can be evaluated when the argument structure is available, i.e., when the verb is processed. Immediate effects of a semantic mismatch between the filler and the verb are expected. The analysis concentrates on three regions of interest: the pre-verb region (region 3, i.e., the subject of the relative clause), the verb region (region 4), and the spillover region (region 5, i.e., adverb).

## 4.2 Results

### 4.2.1 Part 1: Sentence recognition

The sentence recognition experiment was difficult because the sentences that were not from the story differed minimally from the actual sentences on which they were based; thus, accuracies around 70% were to be expected. Table 26 presents the accuracy by story exposure group condition.

Table 26. Percent accurate recognition and standard error by story exposure group.

| *Story Exposure Group* | *Accuracy* | *SE* |
|---|---|---|
| Direct object gap sentences | 71.2% | 6.5% |
| Prepositional object gap sentences | 73.8% | 6.4% |

There was no significant accuracy difference between the two groups ($\beta = 0.14$, $Z = 0.96$, $p > 0.1$). The fact that participants successfully identified the sentences almost three-quarters of the time and did not differ based on exposure group suggests that both groups were reading the stories carefully enough to identify fairly minimal changes.

### 4.2.2 Part 2: Eye tracking

Comprehension accuracy for the target trials was 93.9%, and trials during which participants answered the comprehension question incorrectly were removed from the analysis, as these trials likely reflect distracted reading.

For each reading time measure (i.e., first fixation, first pass, and regression path duration) and each region, reading times longer than three standard deviations greater than the mean were excluded. This resulted in 1.7% of the data being excluded. Table 27 presents the participant means on each measure for each region of analysis as well as the standard errors of the participant means; Figure 13 presents the same data in graphical form. Table 28 presents a summary of the statistical analysis.

Table 27. Experiment 5 participant mean reading times in milliseconds (standard error) and percent regressions.

| Measure | *Pre-Verb Region* | *Verb Region* | *Spillover Region* |
|---|---|---|---|
| **First fixation duration** | | | |
| DO-gap exposure, Plausible | 211 (4) | 259 (6) | 237 (6) |
| DO-gap exposure, Implausible | 215 (4) | 256 (8) | 242 (9) |
| PO-gap exposure, Plausible | 199 (5) | 237 (5) | 225 (6) |
| PO-gap exposure, Implausible | 206 (5) | 246 (5) | 241 (6) |
| **First pass time** | | | |
| DO-gap exposure, Plausible | 342 (14) | 299 (10) | 278 (9) |
| DO-gap exposure, Implausible | 324 (10) | 303 (9) | 296 (15) |
| PO-gap exposure, Plausible | 314 (13) | 283 (7) | 279 (11) |
| PO-gap exposure, Implausible | 335 (11) | 289 (8) | 288 (8) |
| **Regression path time** | | | |
| DO-gap exposure, Plausible | 469 (22) | 346 (11) | 380 (16) |
| DO-gap exposure, Implausible | 466 (19) | 372 (13) | 396 (16) |
| PO-gap exposure, Plausible | 469 (18) | 320 (10) | 336 (15) |
| PO-gap exposure, Implausible | 449 (18) | 345 (14) | 401 (15) |
| **Percent regressions** | | | |
| DO-gap exposure, Plausible | 23.5 (2.3) | 10.7 (1.4) | 17.5 (2.1) |
| DO-gap exposure, Implausible | 24.8 (2.3) | 14.5 (1.9) | 22.4 (2.1) |
| PO-gap exposure, Plausible | 27.3 (2.5) | 7.4 (1.1) | 11.5 (1.4) |
| PO-gap exposure, Implausible | 17.7 (2.5) | 9.7 (1.6) | 21.8 (2.2) |

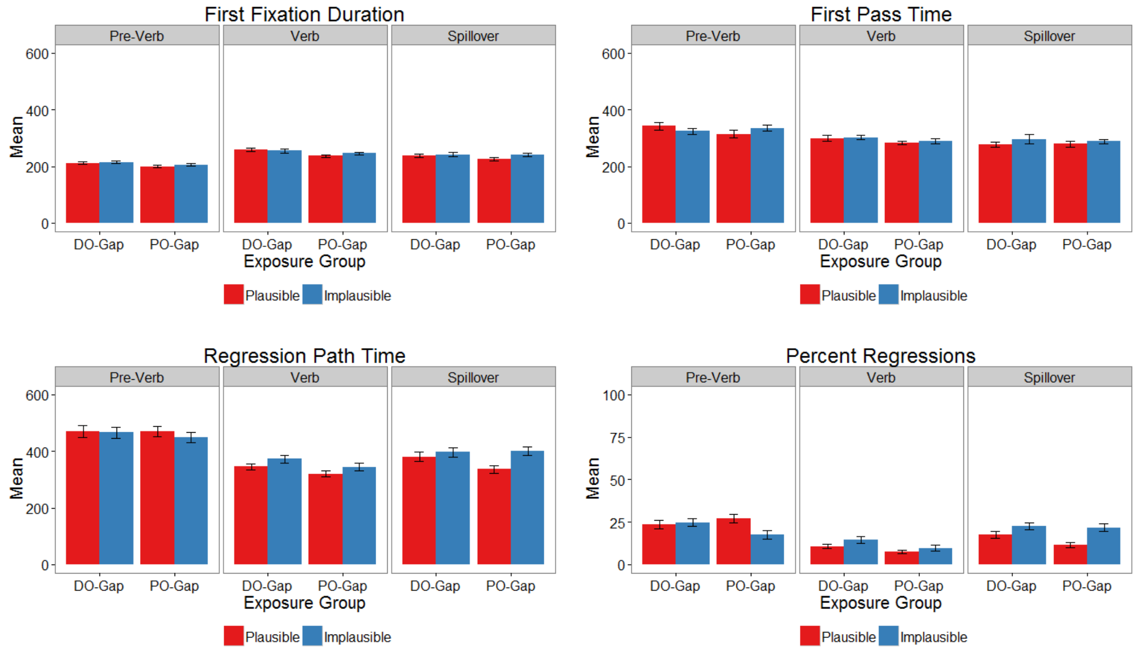



Figure 13. Participant mean reading times in milliseconds and percent regressions by region, exposure group, and plausibility for Experiment 5. Error bars represent ±1 standard error.

In the pre-verb region (i.e., the subject of the relative clause), there was a significant interaction of story exposure group and plausibility in both first pass times ($p < 0.05$) and percent regressions ($p < 0.05$). Planned pairwise comparisons, however, indicated that there was no significant difference in first pass time based on plausibility for either the DO-gap exposure group ($\beta = 19.13$, $SE = 15.99$, $p > 0.1$) or the PO-gap exposure group ($\beta = -23.53$, $SE = 14.66$, $p > 0.1$). On the other hand, planned pairwise comparisons for percent regressions indicated no significant difference based on plausibility for the DO-gap exposure group ($\beta = -0.13$, $SE = 0.23$, $p > 0.1$), but significantly more regressions from this region in the PO-gap exposure condition when the filler was a plausible direct object of the verb ($\beta = 0.79$, $SE = 0.33$, $p < 0.05$).

Table 28. Summary of model estimates, standard errors, and *t*-values (for linear mixed effect models) and *Z*-values (for logit mixed effect models) for the eye movement measures in Experiment 5.

| | *Pre-Verb Region* | | | *Verb Region* | | | *Spillover Region* | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) | *β* | SE | *t* (*Z*) |
| **First fixation duration** | | | | | | | | | |
| Intercept | 207.98 | 4.24 | 49.03*** | 248.88 | 5.84 | 42.64*** | 236.47 | 6.92 | 34.15*** |
| Exposure Group | -10.49 | 8.10 | -1.30 | -16.31 | 11.62 | -1.40 | -7.44 | 12.84 | -0.58 |
| Plausibility | -4.67 | 4.56 | -1.03 | -2.39 | 6.70 | -0.36 | -10.01 | 5.64 | -1.78† |
| Exposure x Plausibility | -2.40 | 8.75 | -0.28 | -11.87 | 12.37 | -0.96 | -9.23 | 11.36 | -0.81 |
| **First pass time** | | | | | | | | | |
| Intercept | 329.76 | 16.44 | 20.06*** | 292.67 | 9.27 | 31.58*** | 285.10 | 11.63 | 24.51*** |
| Exposure Group | -8.70 | 22.04 | -0.40 | -15.73 | 15.13 | -1.04 | -3.49 | 20.65 | -0.17 |
| Plausibility | -1.82 | 10.78 | -0.17 | -3.23 | 9.92 | -0.33 | -13.52 | 9.28 | -1.46 |
| Exposure x Plausibility | -42.20 | 20.84 | -2.03* | -6.36 | 17.02 | -0.37 | 10.92 | 18.39 | 0.59 |
| **Regression path time** | | | | | | | | | |
| Intercept | 461.61 | 26.21 | 17.61*** | 345.13 | 13.35 | 25.85*** | 378.62 | 19.53 | 19.39*** |
| Exposure Group | -9.02 | 35.41 | -0.26 | -26.33 | 20.90 | -1.26 | -10.40 | 28.86 | -0.71 |
| Plausibility | 14.07 | 22.61 | 0.62 | -21.62 | 14.13 | -1.53 | -38.24 | 17.95 | -2.13* |
| Exposure x Plausibility | 14.52 | 33.28 | 0.44 | 11.42 | 36.48 | 0.31 | -43.51 | 29.59 | -1.47 |
| **Percent regressions** | | | | | | | | | |
| Intercept | -1.33 | 0.13 | -10.25*** | -2.28 | 0.16 | -14.16*** | -1.72 | 0.17 | -9.97*** |
| Exposure Group | -0.10 | 0.23 | -0.45 | -0.40 | 0.23 | -1.73† | -0.33 | 0.24 | -1.37 |
| Plausibility | 0.28 | 0.18 | 1.61 | -0.32 | 0.22 | -1.48 | -0.55 | 0.18 | -3.13** |
| Exposure x Plausibility | 0.72 | 0.33 | 2.18* | 0.26 | 0.44 | 0.60 | -0.56 | 0.35 | -1.58 |

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$

In the critical verb region, there was only a marginal effect of exposure group on percent regressions ($p < 0.1$); participants exposed to DO-gaps were more likely to regress out of this region. While we did not find effects of plausibility in the critical verb region, results from the spillover region suggest that the plausibility manipulation was successful. In this region, sentences with implausible fillers had marginally longer first fixation durations ($p < 0.1$), significantly longer regression paths ($p < 0.05$), and significantly more regressions ($p < 0.01$). This main effect was not tempered by any interactions for any of the analyzed eye tracking measures (all *ps* > 0.1). Thus, the plausibility mismatch effect was visible in reading times on the spillover region, but was not affected by exposure to PO-gap sentences.

## 4.3 Discussion

Experiment 5 examined whether the syntactic adaptation effects observed in Experiment 3 could be induced by a more naturalistic exposure environment. In Experiment 3, the PO-gap sentences were presented in a single block and may have lead participants to generate an experiment-specific expectation about the types of sentences that would appear later in the experiment. Experiment 5 suggests that this is a plausible explanation for the diminished active gap filling in Experiment 3. When the exposure block was disguised as a separate experiment (with separate experimental goals), the group exposed to PO-gap sentences no longer demonstrated decreased active gap filling. Like the DO-gap exposure group, they read the region following the verb more slowly when the filler was an implausible direct object of the verb. This suggests that both groups were actively associating the filler with the verb, and were surprised when the semantic fit between the verb and the filler did not allow the direct object gap interpretation.

While the above results suggest that syntactic adaptation of filler-gap dependency processing does not generalize across experiments, there are additional differences between Experiments 3 and 5 besides the presentation of the exposure block. Specifically, the target sentences in Experiment 3 probed the filled gap effect: a reading time slowdown on a direct object noun phrase. Conversely, Experiment 5 utilized the plausibility mismatch effect, which tests the effect of a semantic mismatch between the filler and the verb. The fact that the form of the target sentences seems to be important suggests that the syntactic adaptation effect from Experiment 3 may not generalize from a structural test of active gap filling (i.e., direct object filled gap sentences, which syntactically block a direct object gap interpretation) to a semantic test of the same (i.e., plausibility mismatch sentences, which semantically block a direct object gap interpretation).

## 5 Overall Discussion

The set of experiments in this chapter aimed to test whether adults adapt their syntactic predictions during filler-gap dependency processing to reflect the input. Experiment 3 explored the hypothesis provided by the probabilistic parsing account that adults should adjust their gap predictions during their real time filler-gap dependency processing to reflect the distribution of gap positions in the input. The results of this experiment demonstrated that exposure to prepositional object gaps does decrease direct object gap predictions. Experiment 4 assessed whether this decrease in direct object gap predictions was accompanied by an increase in prepositional object gap predictions, a prediction that matches the structure in the input. The results of this experiment, however, did not reveal prepositional object gap predictions. The final experiment in this chapter, Experiment 5, tested whether the adaptation effect from Experiment 3 would generalize across experimental boundaries. When the exposure to prepositional object gaps was provided as a separate experiment, participants did not modulate their direct object predictions as in the earlier experiment. Taken together, the results of Experiments 3 through 5 suggest that active gap filling can be tempered by concentrated exposure to later gap positions, i.e., prepositional object gaps (Experiment 3), but this weakened association between the filler and the verb does not lead to an active prediction of a prepositional object gap (Experiment 4) nor does it transfer across experiments (Experiment 5). These findings have implications for the representation of syntactic predictions and the future study of adaptation effects.

## 5.1 Representation of syntactic predictions

The combined results of Experiments 3 and 4 suggest that potential gap positions may not be in direct competition with one another. In the original Fine et al. (2013) study, increased expectation of a reduced relative clause, as driven by the input distribution, was accompanied by a decrease in the expectation of a main clause verb. This suggests that the two possible structures are in direct competition, and is unsurprising given that argument structure ambiguity resolution involves selection of a structure from competing options. This competition among structures follows directly from the probabilistic parsing account; probabilities are calculated using the relative frequency of a particular structure compared to other relevant structural options. The decrease in direct object gap predictions demonstrated in Experiment 3, however, did not correspond to an increase in prepositional object gap predictions in Experiment 4. Thus, decreasing the probability of one gap position did not increase the probability of the other gap position despite the fact that prepositional object gaps were attested in the input.

These findings suggest that the effect of exposure to input skewed toward unexpected gap positions, i.e., prepositional object gaps, is to dampen gap predictions in general, rather than to shift them toward the gap position present in the input. The difference between the effect of language experience on ambiguity resolution and filler-gap dependency processing supports my earlier claim that predictions in argument structure ambiguity resolution are not the same type as predictions in filler-gap dependency processing and other cases of pre-building syntactic structure (e.g., Staub &

Clifton, 2006; Yoshida et al., 2013). The presence of unpredictable structures in the input serves different purposes in these interpretative processes. In ambiguity resolution (Fine & Jaeger, 2013), exposure to an *a priori* improbable structure (e.g., a reduced relative clause) results in a shift in the probability distribution in favor of that structure. Conversely, in filler-gap dependency processing, exposure to an unexpected gap position (e.g., prepositional object gaps) dampens syntactic predictions in general.

This difference may also have important implications for the interpretation of corpus analyses. While they are meant to estimate the current probability distribution of syntactic structures in the input, they may only estimate the overall bias for one structure over another for structures that involve syntactic predictions. In the specific case of filler-gap dependencies, it is possible that the distributional analyses presented at the beginning of this chapter (see Section 2) and in Chapter 1 (Section 3) only indicate the overall preference for direct object gaps, which may generate the active gap filling strategy. The results of Experiments 3 and 4 suggest that the violation of this bias does not lead to redistribution of the probability among gap positions, as it would if these distributions were being used dynamically during real time sentence processing. Rather, they suggest a reduction in the application of this bias toward the generation of future predictions.

### 5.2 Implications for syntactic adaptation effects

The results of the three experiments presented in this chapter also have implications for future studies of adaptation effects, particularly those from Experiment 5. Experiment 5 examined whether language experience from one experiment carries over to another experiment in the same session. Specifically, participants were exposed to input skewed toward prepositional object gaps in an initial sentence recognition experiment, and then given the opportunity to apply that distribution in an eye tracking during reading experiment. Unlike in Experiment 3, however, participants did not modulate their direct object gap predictions after being exposed to prepositional object gaps; instead, they continued to actively fill the direct object gap as demonstrated by a plausibility mismatch effect in the spillover region. These results suggest that the distribution of gaps presented in the sentence recognition experiment was not applied when processing filler-gap dependencies in a separate experiment, and that adaptation effects may not generalize outside of specific situations (e.g., a single experimental environment). This finding is also compatible with the suggestion that adaptation is responsible for conversational alignment (Jaeger & Snider, 2013); syntactic adaptation effects may not generalize outside the environment of a single conversation. Therefore, it is possible that the individual studies in Experiment 5 were treated as separate conversational environments, and the distributional information did not transfer for this reason. Future research is required to determine what exactly constitutes a relevant linguistic context for adaptation. For example, this study took place in a single room, but on two different computers. The input from one study may have appeared as relevant for the other if they were administered on the same computer.

# CHAPTER 4 – PRIMING SYNTACTIC PREDICTIONS

## 1 Introduction

The findings from the previous chapter (Chapter 3) demonstrated that adults real time processing of filler-gap dependencies can be affected by the distribution of gap positions in their input at least when that input is presented as part of the same task. This chapter explores whether recent language experience can have a similar effect on children's gap predictions. In particular, this chapter attempts to trigger children's learning of active gap filling by priming them with filler-gap dependencies in their input.

To clarify terminology, theories of expectation adaptation and priming predict similar behaviors, but attribute these behaviors to different causes. Syntactic adaptation effects are usually attributed to an attempt to converge on the specific input statistics (see Fine et al., 2013). Priming, however, is a more general term that allows language experience to influence the structure of future utterances without requiring a match between usage and distributional information. Chapter 3 provided some evidence that gap predictions do not converge on the statistics of the input, so the remainder of this chapter will use the broader term, i.e., syntactic priming, about the following series of experiments.

### 1.1 Syntactic priming in children

As reviewed in Chapter 3, there is evidence for syntactic priming in the production and comprehension processes of adults (see Chapter 3, Section 1.1). A growing body of research has used syntactic priming as a tool to test the abstractness of children's representations and has revealed that children as young as three also demonstrate syntactic priming (Bencini & Valian, 2008; Huttenlocher, Vasilyeva, & Shimpi, 2004;

Rowland, Chang, Ambridge, Pine, & Lieven, 2012; Savage, Lieven, Theakston, & Tomasello, 2003, 2006; Shimpi, Gámez, Huttenlocher, & Vasilyeva, 2007; Thothathiri & Snedeker, 2008b). Also, bilingual children are susceptible to cross-linguistic priming (i.e., priming from one language to the other, Hsin, Legendre, & Omaki, 2013; Vasilyeva et al., 2010).

For example, Huttenlocher, Vasilyeva, and Shimpi (2004) examined priming effects in 4- and 5-year-old children in a series of three studies. In the first study, an experimenter described a picture (e.g., *the rain watered the flower*), the child repeated that description, and then described a new picture. The prime sentences were either transitive constructions (active versus passive) or dative constructions (double object versus prepositional object). Huttenlocher and colleagues found that children were more likely to produce the structure that matches the one used by the experimenter. Children produced more active sentences after repeating an active sentence and more passives after repeating a passive. Similarly, they produced more double object datives after repeating a double object dative and more prepositional object datives after repeating that structure. In two follow-up studies, children demonstrated these same priming effects without repetition of the experimenter's utterance (comprehension to production priming) and following a block of 10 prime sentences (priming after a delay). These findings suggest that 4-year-olds are subject to the same bias to repeat the syntax of a previous utterance as adults.

Additionally, Thothathiri and Snedeker (2008b) examined the effects of syntactic priming on children's real time comprehension behaviors. This developmental study is based on their adult comprehension priming experiments (Thothathiri & Snedeker, 2008a) as described in the previous chapter (see Chapter 3, Section 1.1.1). Three- and four-year-olds were instructed to interact with the objects in a visual scene using either a double object (DO) or prepositional object (PO) dative structure. In the targets, the form of the noun phrase following the verb induced a temporary argument structure ambiguity (DO: *Give the* ***bird*** *the dog bone*; PO: *Give the* ***bird*** *house to the sheep*). An animate NP (e.g., *bird*) is compatible with the DO structure, while an inanimate NP (e.g., *bird house*) is compatible with the PO structure. Both within and across verbs, children primed with DO datives looked more toward the animate recipient than the inanimate theme during the ambiguous region and vice versa for participants primed with PO datives. These results demonstrate that children as young as 3 utilize the structure of a previous utterance to inform their processing of an upcoming utterance and, in turn, their interpretation of temporarily ambiguous NPs.

Taken together, these results suggest that, like the adults in Chapter 3, children's processing behavior may be susceptible to the effect of language experience. In the next section, I review theories of priming that attribute it to a form of implicit learning and suggest priming as a possible mechanism for children to learn to process filler-gap dependencies like adults.

### 1.2 Priming and syntactic adaptation as implicit learning

A prominent psycholinguistic theory attributes priming and adaptation effects to an implicit learning mechanism (Bock & Griffin, 2000; Chang, Dell, & Bock, 2006; Chang, Dell, Bock, & Griffin, 2000; Fine & Jaeger, 2013; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Jaeger & Snider, 2013). Initially, it was proposed that priming is a boost in the transient activation of the primed structure (Bock, 1986;

Pickering & Branigan, 1998). Pickering and Branigan (1998) suggest an account of priming based on a model of lexical knowledge in which nodes representing verbs are directly connected to combinatorial nodes that represent the structural options made available by that verb. For example, the node representing the ditransitive verb *give* is connected to a node representing the double object dative structure and to a node representing the prepositional object dative. When a verb is used in a particular structure, the link between the verb node and the associated combinatorial node are activated. Activation of these nodes only gradually decays; they suggest that it is this short-term activation above baseline that leads to priming effects. If a DO dative is processed, e.g., *give the dog a bone*, the nodes for the verb *give*, the DO dative structure, and their connection are activated. Because the DO dative structure is activated above baseline, it is more likely to be chosen when the following utterance also requires a dative structure.

Contra this transient activation theory, other theorists suggest that priming represents more substantial learning. If priming were grounded in transient activation, priming effects should also be transient. However, studies have shown that priming effects can persist over periods longer than a single trial for adults (e.g., Bock & Griffin, 2000; Kaschak, 2007; Kaschak et al., 2014, 2006) and children (Huttenlocher et al., 2004; Savage et al., 2006). Bock and Griffin (2000) tested priming of passives and the dative alternation across several lag lengths (i.e., number of sentences between the prime and the target). In this study, the prime trials were presented auditorily and repeated by participants, while the target trials were pictures that the participants described. Across lags of 2 and 10 intervening sentences, participants demonstrated priming effects for both passives and the dative alternation. Because priming persists across a multi-sentence lag, it cannot solely be the result of an increase in the transient activation of the structure of the prime. Furthermore, Bock and Griffin suggest that syntactic priming is a form of learning that arises from the language acquisition mechanisms themselves.

Though the persistence of priming effects across a 10 trial lag may not seem like a long enough period to suggest a significant learning effect, Savage et al. (2006) examined long term priming effects in 4-year-olds and demonstrated that priming effects persisted for up to a month. In this experiment, 4-year-olds were primed with passives (e.g., *it got pushed by it*) and tested after varying lengths of time. One group was tested immediately, after a week, and after a month and another was tested immediately and after a month. The variability of the prime sentences was also manipulated. Some children were exposed to identical passive primes, while others were exposed to varied primes (using different verbs). Both of these factors had a significant effect on priming. The group exposed to varied passive primes demonstrated stronger priming effects than the group exposed to identical primes. Also, priming effects persisted for up to a month, but only for the children who received varied input reinforced by a test a week after priming. The fact that priming was sensitive to varied input and reinforcement suggested that children learned from the primes and updated their linguistic representations accordingly. These results suggest a much stronger connection between priming and learning. In this chapter, this link is explored with respect to the priming of gap positions and the development of active gap filling.

## 1.3 The current studies

In this chapter, two priming studies (comprehension and production) investigate whether priming could be a mechanism for the development of syntactic predictions in filler-gap dependency processing. Comprehension priming may be more similar to the real-life learning process, but previous priming studies and the results of Experiment 5 on cross-study expectation adaptation suggest it may not be as effective as production priming. For this reason, both comprehension (Experiment 6) and production (Experiment 7) priming are going to be explored.

In the visual world investigation of children's active gap filling (Experiment 1), 5- to 7-year-olds did not reliably predict a direct object gap when processing *wh*-questions. These studies focus on the youngest of these children, 5-year-olds, because if active gap filling can be primed at this age, it seems reasonable to believe it would successfully prime direct object gap predictions in the older children as well.

# 2 Experiment 6 – Comprehension priming

Comprehension priming potentially reflects naturalistic learning processes in which children learn about language and parsing biases from the structures to which they are exposed in the input. Thus, this study examines priming through comprehension as a potential triggering mechanism for active gap filling using a novel picture completion task designed to elicit *wh*-questions from children and the visual world eye tracking design from Experiment 1.

## 2.1 Method

### 2.1.1 Participants

Thirty-two English speaking children between the ages of 5;0 and 6;1 (mean = 5;6, 17 females) participated in this study. These children were recruited from the communities surrounding Johns Hopkins University and the greater Baltimore area. Six additional children participated but their data was excluded from the analyses due to a speech delay

($n$ = 1), failure to cooperate ($n$ = 1), and lack of attention (indicated by incorrect answers to more than a quarter of the questions, $n$ = 4).

Additionally, 32 adult native speakers were recruited from the undergraduate population at Johns Hopkins University participated as a comparison group and received course credit for their participation.

### 2.1.2 Materials

#### *2.1.2.1 Picture completion task*

A novel picture completion task was designed to elicit *wh*-questions. This task was presented as a game played by the child participant and a confederate experimenter. Participants and a confederate experimenter each had pages depicting the same events, but with parts of the events missing. The participant and the confederate experimenter asked each other questions to complete their matching pictures. Each picture page was associated with a verb (draw, wash, collect, water, and cook) and consisted of five events with the same agent (see e.g., Figure 14). Each event contained an object (e.g., a picture of a house), an instrument (e.g., a pencil), and a location (e.g., a desk). Three versions of each page were created using this basic template: one version removed the objects (Figure 14), one version removed the instruments (Figure 15), and one version in which the agent, object, and instrument were removed together from their location (Figure 16). The associated "stickers" that complete these pages are also presented in the figures.

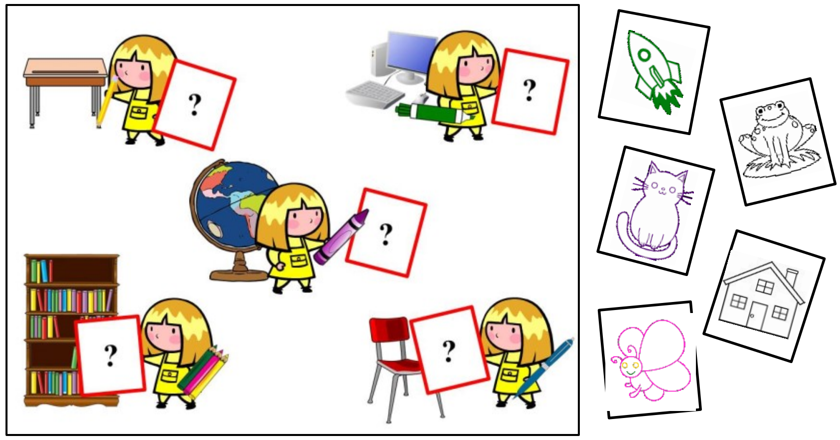



Figure 14. Example page from the picture completion task depicting drawing events with missing objects. To the right of the page are the associated stickers of the objects (rocket ship, frog, cat, house, and butterfly).

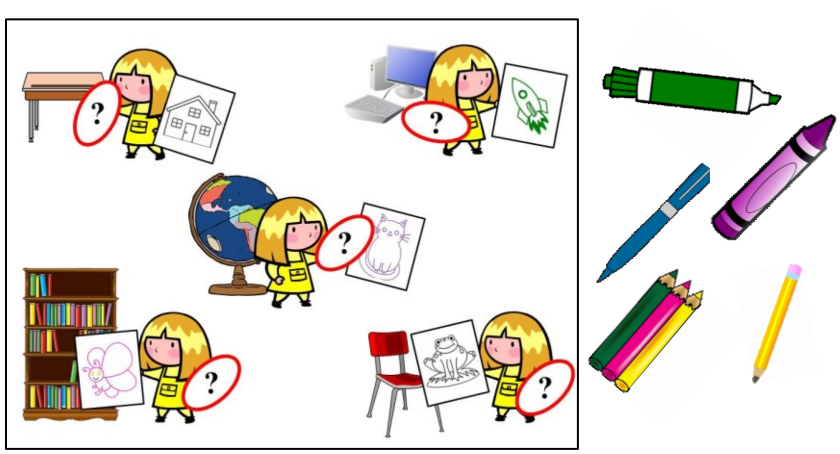



Figure 15. Example page from the picture completion task depicting drawing events with missing instruments. To the right of the page are the associated stickers of the instruments (marker, pen, crayon, colored pencils, and pencil).

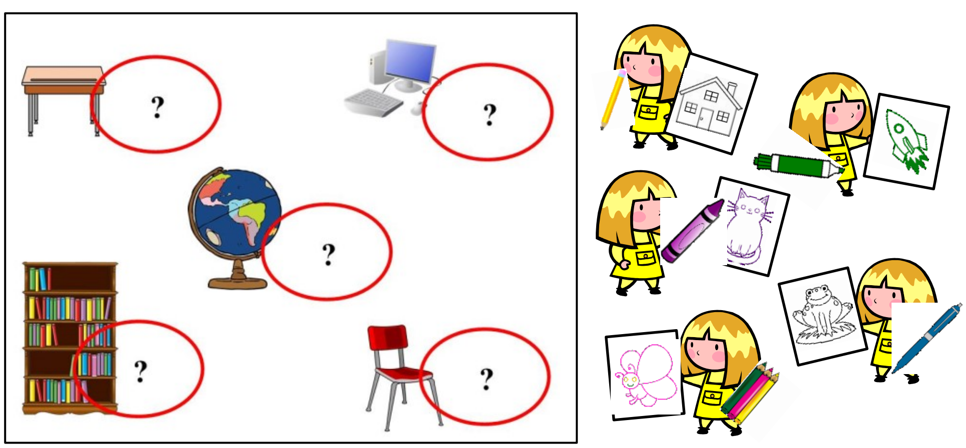



Figure 16. Example page from the picture completion task depicting drawing events. These events are removed from their locations. To the right of the page are the associated event stickers.

To complete the page in Figure 14 in which the objects are missing, a direct object gap *wh*-question must be produced (1a). Alternatively, when the instruments are missing, as in Figure 15, a prepositional object gap question must be produced (1b) to complete the page.

(1) a. *Direct Object gap*: What was the girl drawing __ with the pencil?
b. *Prepositional Object gap:* What was the girl drawing the house with __?

In this experiment, the confederate experimenter produced these questions for the child to answer. Children were assigned to one of these comprehension groups: direct object gap (N = 16, mean age = 5;5) or prepositional object gap (N = 16, mean age = 5;6). Each child completed 5 pages, and thus comprehended a total of 25 direct object or prepositional object *wh*-questions. A complete list of the target direct object and prepositional object gap questions is given in Appendix E.

The children's pictures always showed the events separated from their locations, and required the production of *where* adjunct questions to complete. As the structure of these questions was not critical, the form of children's *where* questions was not strictly enforced. For the question to be accepted, the child simply had to use the *wh*-phrase *where* and communicate the intent of the question to the confederate experimenter. For example, the questions in (2) were all acceptable ways to ask about the location of the "drawing a cat with a crayon" event.

(2) a. Where was the girl drawing the cat?
b. Where was the girl drawing with the crayon?
c. Where was the girl drawing the cat with the crayon?
d. Where was the girl using the crayon?
e. Where was the girl with the crayon drawing?

#### *2.1.2.2 Visual world eye tracking*

The materials for the visual world eye tracking portion of the experiment were identical to those from Experiment 1 (see Chapter 2, Section 2.1.2). The experiment consisted of 20 stories (10 targets, 10 fillers) accompanied by associated visual world displays. Each story consisted of a subject completing two events consisting of an object and an instrument (e.g., eating cake with the fork). The displays consisted of 5 images depicting the subject, the object and instrument of the first event, and the object and instrument of the second event. Each story was followed by a *wh*- or *yes-no* question. The target questions consisted of a temporarily ambiguous *wh*-question, e.g., (3a), and its *yes-no* question counterpart, e.g., (3b).

(3) Can you tell me…
    a. *Wh-Question:* …what Emily was eating the cake with __?
    b. *Yes-No Question:* …if Emily was eating the cake with the fork?

### 2.1.3 Procedure

#### *2.1.3.1 Picture completion task*

In addition to the child and the confederate experimenter, an organizing experimenter explained the task, provided instructions, and facilitated the question asking portion. An occluder was set up between the child and the confederate experimenter so that the child could not see what was on the confederate's page and vice versa, see Figure 17.

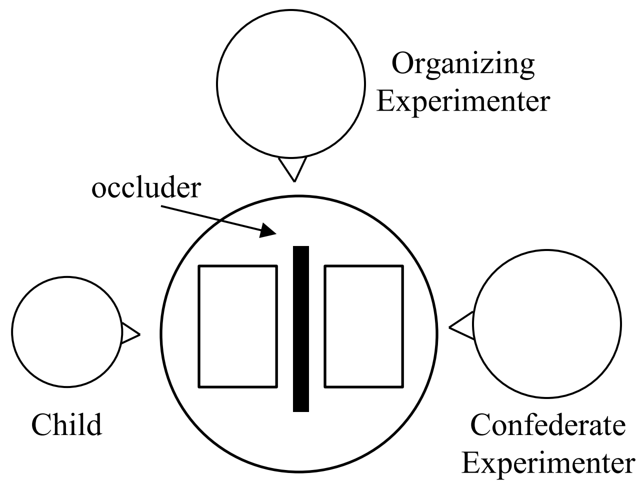



Figure 17. Experimental arrangement for the picture completion task. The child participant and confederate experimenter sat on opposite sides of an occluder, while the organizing experimenter sat at the top where she could see both sides and facilitate the question-asking game.

The organizing experimenter explained that the goal of the task was for the child and the confederate experimenter to make matching pictures, and the task began with a practice session. The practice page only had two events, and was used to demonstrate the target adjunct *where*-questions (*Where did the boy eat the soup?*). It also gave the child an opportunity to practice producing the adjunct questions and answering the confederate experimenter's direct object or prepositional object *wh*-questions.

For each trial, the organizing experimenter distributed the pages, introduced the associated verb, labeled the locations, and described in full each of the events using the associated sticker (e.g., *Here, the girl is drawing a cat with a crayon*). A verb was associated with each page to enforce uniformity in productions, to provide a reason for the confederate experimenter to repeat that verb in her productions, and to ease children's production processes by providing a verb. After this introduction to the page, the confederate experimenter asked all 5 of her target *wh*-questions and completed her picture before the child asked any questions. Once the confederate experimenter had completed her page, the child participant was prompted to ask her adjunct questions by the organizing experimenter; the child was free to choose in which order these questions were asked. The confederate experimenter answered all 5 of the child's *where* questions, and the child completed her picture..

At the end of the trial, the organizing experimenter lifted the occluder so that the child and the confederate experimenter could compare their pages, and the child could see that they had made matching pictures. Audio and video of each session was recorded on an Olympus WS-822 audio recorder and a Sony Handycam video camera for use in coding the data.

#### *2.1.3.2 Visual world eye tracking*

The procedure for the visual world eye tracking phase of the experiment was identical to that from Experiment 1 (see Chapter 2, Section 2.1.3). The experiment began with a practice story after which children were asked a *wh*-question, a *yes-no* question with a "yes" answer, and a *yes-no* question with a "no" answer. For the experimental trials, children first heard short, two event stories while associated pictures were displayed on the screen. Following the story, children fixated on a central position on the screen for 1000ms so that they were looking at the screen when the question began. After the fixation, the display screen returned and the audio for the associated question played. Children answered these questions out loud, then the experimenter provided positive reinforcement (regardless of accuracy) to keep the child engaged and the next trial began.

### 2.1.4 Data Analysis

#### *2.1.4.1 Picture completion task*

Children's adjunct question productions were the fillers in this experiment and therefore were fairly heterogeneous. Rather than enforcing a specific structure, the experimenter allowed any questions that began with *where* and conveyed which event the child was asking about, see (2). All children were able to produce some version of the location questions that elicited the correct response from the confederate experimenter. Given that the critical questions are those produced by the confederate experimenter, children's utterances were not coded in this experiment.

#### *2.1.4.2 Visual world eye tracking*

The analysis procedure for the visual world eye tracking study was similar to that from Experiment 1 (see Chapter 2, Section 2.1.4). As in Experiment 1, trials during which participants fixated disproportionately on the blank areas of the screen were excluded. For the adults, 40% or greater of their fixations were required to be on one of the five pictures; for the children, 35% was required.

The empirical logit (Barr, 2008) was calculated for fixation data from the two analysis regions – the verb and object NP regions – aggregated into 50ms bins, and linear mixed effect models were fit to age groups (adults and 5-year-olds) individually before conducting an overall analysis. The analyses were conducted on the separate age groups first because priming was expected to have differing effects on these age groups. For adults, it is the prepositional object gap primes that are expected to affect real time gap predictions. PO gap comprehension should dampen direct object gap predictions in much the same way as exposure to PO gaps did in Experiment 3. For 5-year-olds, on the other hand, it is the direct object gap primes that are predicted to have an effect. Priming of direct object gaps is hypothesized to trigger active gap filling in 5-year-olds, while prepositional object gap primes should not alter their baseline behavior (i.e., a lack of active gap filling as demonstrated in Experiment 1).

These separate age group analyses had question type (*wh*- vs. *yes-no* questions), comprehension group (DO gap vs. PO gap production), and time as fixed effects and random intercepts for participants and items. Planned pairwise comparisons within age group evaluated the effect of comprehension group. The DO gap and PO gap comprehension groups were isolated and individually fit to another linear mixed effect model with question type and time as fixed effects and random intercepts for participants and items. Finally, the overall linear mixed effect model evaluated the differences between the age groups; the model used question type, comprehension group, and age group (adults vs. 5-year-olds) as fixed effects with random intercepts for participants and items.

## 2.2 Results

### 2.2.1 Question accuracy

Adults were almost 100% accurate at answering the questions after the stories. One adult answered a single, filler question incorrectly (i.e., was 95% accurate); all other adults were 100% accurate. Overall, the 5-year-olds were 95% accurate, and no child was less than 80% accurate (i.e., no more than 4 incorrect answers). Eight of these incorrect answers were to target questions, so these trials were excluded from the analysis (8 out of 320, 2.5%).

### 2.2.2 Eye tracking data

*Adults.* Ten of the 320 target trials (~3%) were excluded for failure to surpass the 25% criterion for minimum duration of fixations on the images. Including the trial excluded for inaccuracy, a total of 11 adult target trials (~3%) were excluded.

As in Experiment 1, adults fixate on the pictures as they are named. Time course data for each comprehension group (DO gap vs. PO gap comprehension) are presented separately. Figure 18 presents the fixation data for the adults in the DO gap comprehension group in the *wh*-question condition, and Figure 19 presents the same group's fixation data for the *yes-no* question condition.

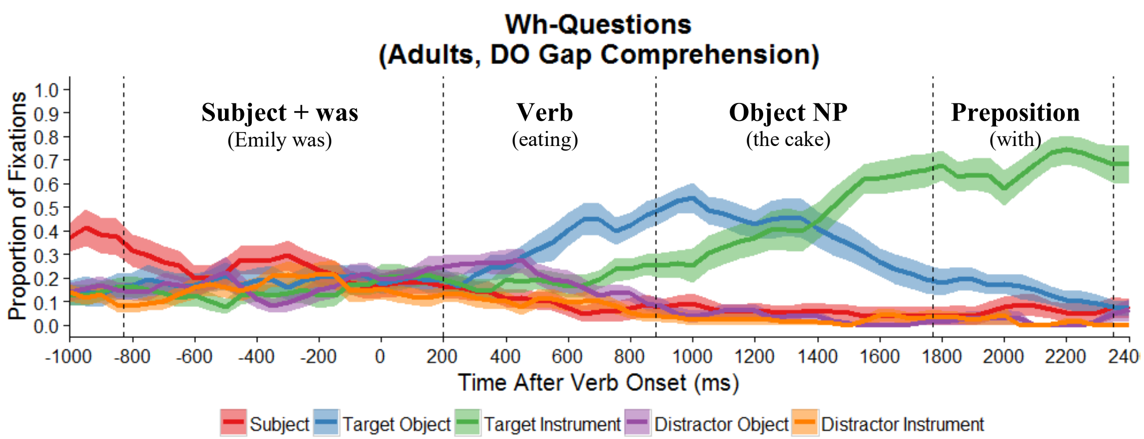



Figure 18. Proportion of fixations to the displayed items in the *wh*-condition for adults in the DO gap comprehension group. Shaded areas indicate ±1 standard error.

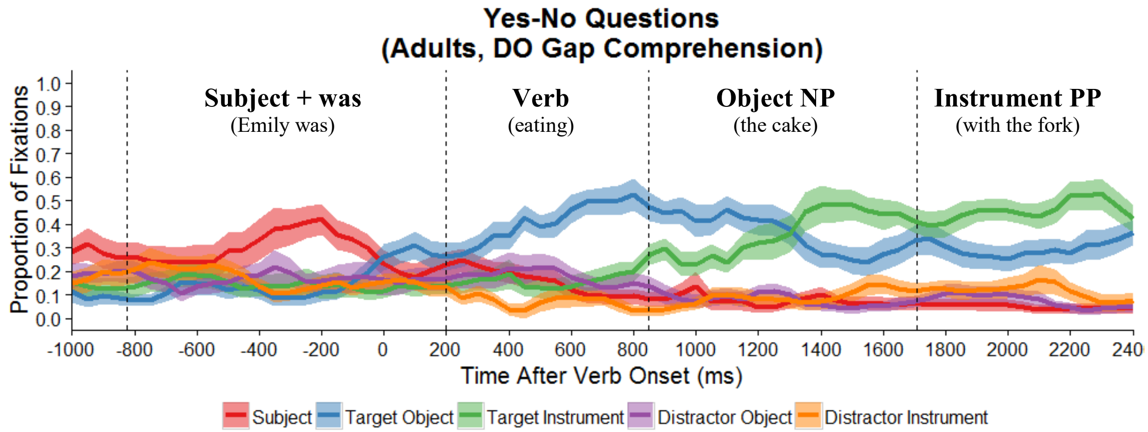



Figure 19. Proportion of fixations to the displayed items in the *yes-no* condition for adults in the DO gap comprehension group. Shaded areas indicate ±1 standard error.

The time course data for the adults in the PO gap comprehension group is given in Figure 20 (*wh*-questions) and Figure 21 (*yes-no* questions).

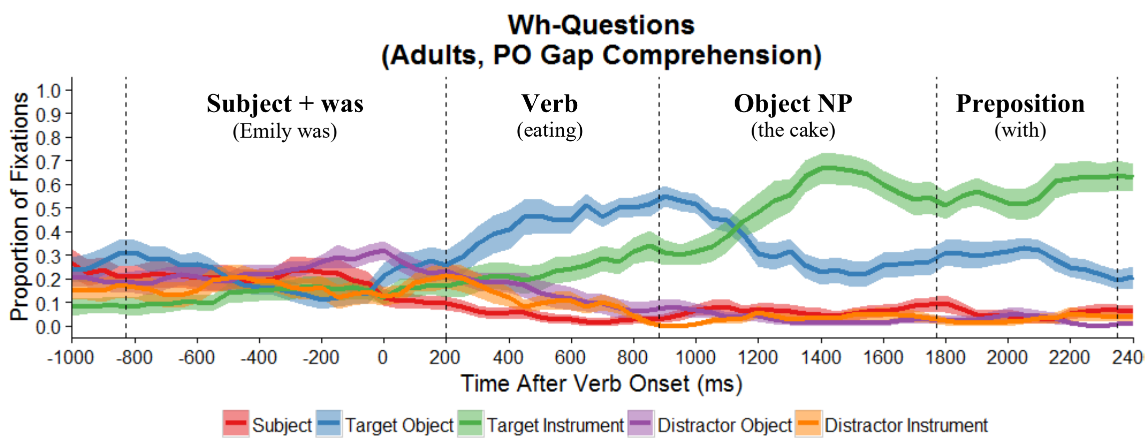



Figure 20. Proportion of fixations to the displayed items in the *wh*-condition for adults in the PO gap comprehension group. Shaded areas indicate ±1 standard error.

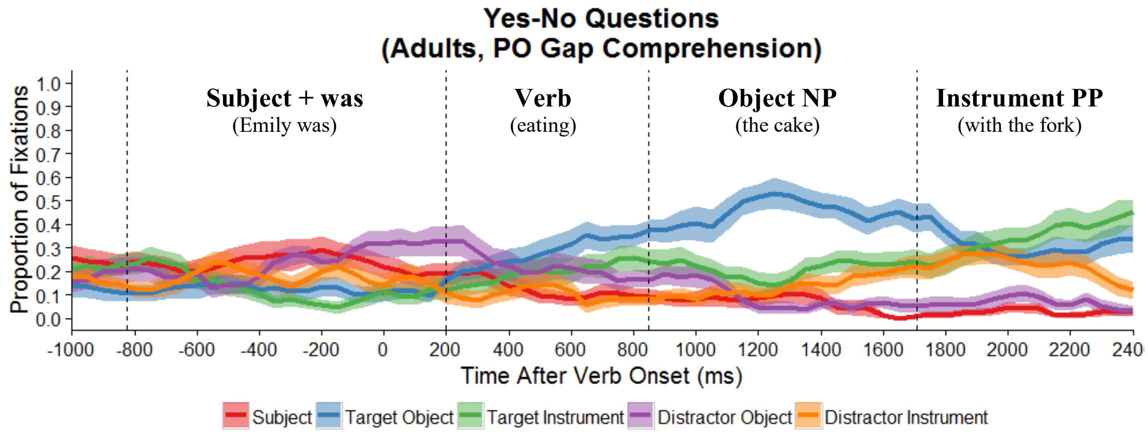



Figure 21. Proportion of fixations to the displayed items in the *yes-no* condition for adults in the PO gap comprehension group. Shaded areas indicate ±1 standard error.

In both comprehension groups and for both question types, the fixations on the target object (e.g., *cake*) increased in the verb region. From visual inspection it is unclear if there are any differences in these increased fixations based on question type. To examine this issue, Figure 22 isolates adults' fixations on the target object during the verb region separated by question type and comprehension group.

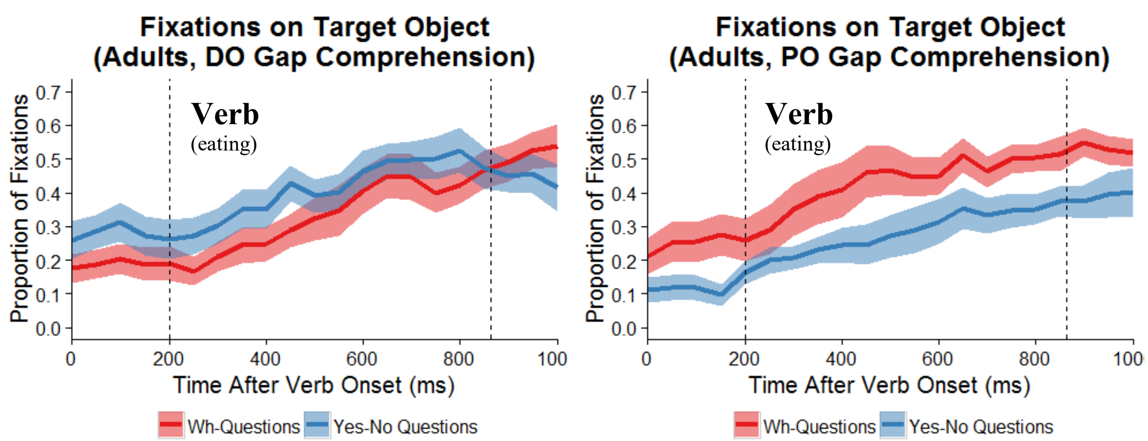



Figure 22. Adults' proportion of fixations on the target object in the verb region for both comprehension groups and question types. Shaded areas indicate ±1 standard error.

In the verb region, the interaction of question type (*wh-* versus *yes-no* questions) and comprehension group (DO gap versus PO gap) had a significant effect on the intercept ($\beta$ = -1.43, $SE$ = 0.51, $p$ < 0.001). None of the examined factors had a significant effect on the slope. Planned pairwise comparisons revealed that adults in the DO gap comprehension group were significantly more likely to be fixating on the target object at the onset of the verb region in *yes-no* questions ($\beta$ = -0.76, $SE$ = 0.36, $p < 0.05$). The effect of question type on the slope was not significant ($\beta$ = 0.84, $SE$ = 0.63, $p > 0.1$).

Conversely, adults in the PO gap comprehension group were significantly more likely to be fixating on the target object at the onset of the verb region in *wh*-questions ($\beta$ = 0.69, $SE$ = 0.36, $p$ = 0.05). Again, question type did not significantly effect the slope ($\beta$ = -0.10, $SE$ = 0.62, $p > 0.1$). Thus, adults in the PO gap comprehension group seem to be predicting a direct object gap, and doing so less than 200ms after the onset of the verb. Adults in the DO gap comprehension group, however, did not demonstrate active gap filling at the verb.

As in Experiment 1, there is an additional region that can reveal gap predictions: the object NP. In the object NP region, adults in both comprehension groups increase their fixations on the target instrument. This increase is greater in the *wh*-questions for both groups (Figure 18 and Figure 20). Figure 23 isolates adult's fixations on the target instrument in the object NP region separated by question type and comprehension group.

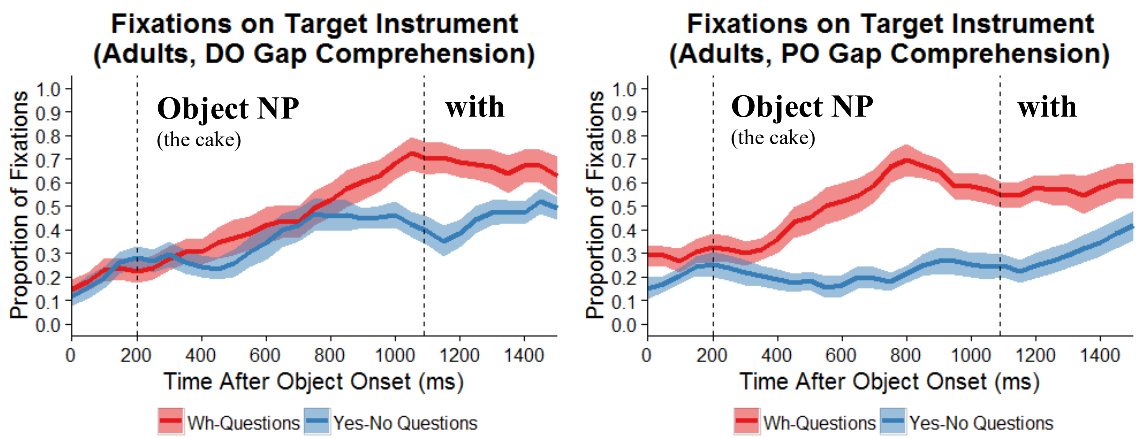



Figure 23. Isolation of the adults' proportion of fixations on the target instrument in both question type conditions separated by comprehension group. Shaded areas indicate ±1 standard error.

In this region, there were no significant effects on the intercept. However, there was a significant effect of question type ($\beta$ = 1.93, *SE* = 0.29, $p$ < 0.001) and comprehension group ($\beta$ = 0.68, *SE* = 0.29, $p$ < 0.05) on the slope. These results indicate that adults increased their fixations on the target instrument in the object NP region more quickly during *wh*-questions. Also, adults in the DO gap comprehension group increased their fixations on the target instrument more quickly than the PO gap comprehension group.

Planned pairwise comparisons revealed a marginal effect of question type on the intercept for the DO gap comprehension group ($\beta$ = -0.50, *SE* = 0.28, $p$ < 0.01), which indicated that participants in this group were more likely to be fixating on the target instrument at the onset of the object NP region in the *yes-no* question condition. There was also a significant effect of question type on the slope ($\beta$ = 1.52, *SE* = 0.41, $p$ < 0.001), which counteracts the marginal effect on the intercept. The effect on the slope indicated that fixations on the target instrument increased more quickly in the *wh*-

question condition, and that participants in this group were predicting a prepositional object gap during the object NP region.

For the PO gap comprehension group, the effect of question type on the intercept was not significant ($\beta$ = -0.03, *SE* = 0.28, $p > 0.1$). Similar to the DO gap comprehension group, there was a significant effect of question type on the slope ($\beta$ = 2.48, *SE* = 0.42, $p < 0.001$). Participants in this group increased their fixations on the target instrument more quickly in the *wh*-question condition. As before, this pattern of results suggests that adults were predicting a prepositional object gap during the object NP region.

Overall, adults in the DO gap comprehension group did not demonstrate active gap filling at the verb, while adults in the PO gap comprehension group demonstrated active gap filling at the verb on a faster time scale than usual (i.e., their anticipatory fixations began less than 200ms after the onset of the verb, compare to Experiment 1). Both comprehension groups predicted a prepositional object gap during the object NP region.

*5-year-olds.* Two 5-year-olds were excluded from the final analysis on the basis of their differences scores in the verb region (see Chapter 2, Section 2.1.4), which were outside 2 standard deviations from the mean difference score (mean = -0.01, *SE* = 0.03). Thus, the data from 30 children were included in further analyses. Fifteen of the 300 target trials (5%) were excluded for failure to surpass the 30% criterion for minimum duration of fixations on the images in the display. Including the eight target trials that were excluded for inaccuracy, a total of 23 of the 5-year-old's target trials were excluded (~8%).

As in all other versions of the visual world study, 5-year-olds in Experiment 7 fixate on the pictures as they are named (see also Altmann & Kamide, 1999; Sussman & Sedivy, 2003). The time course fixation data for the children in the DO gap comprehension group is presented in Figure 24 (*wh*-questions) and Figure 25 (*yes-no* questions).

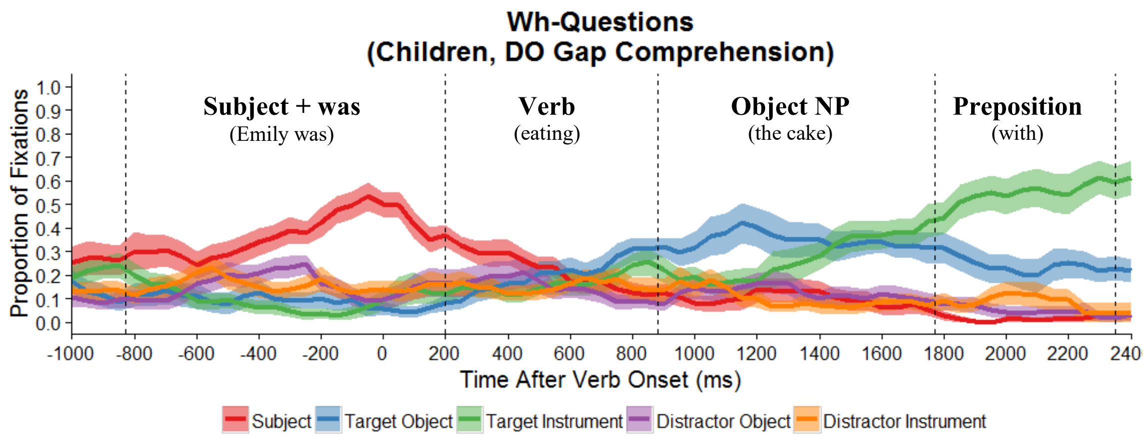



Figure 24. Proportion of fixations to the displayed items in the *wh*-condition for 5-year-olds in the DO gap comprehension group. Shaded areas indicate ±1 standard error.

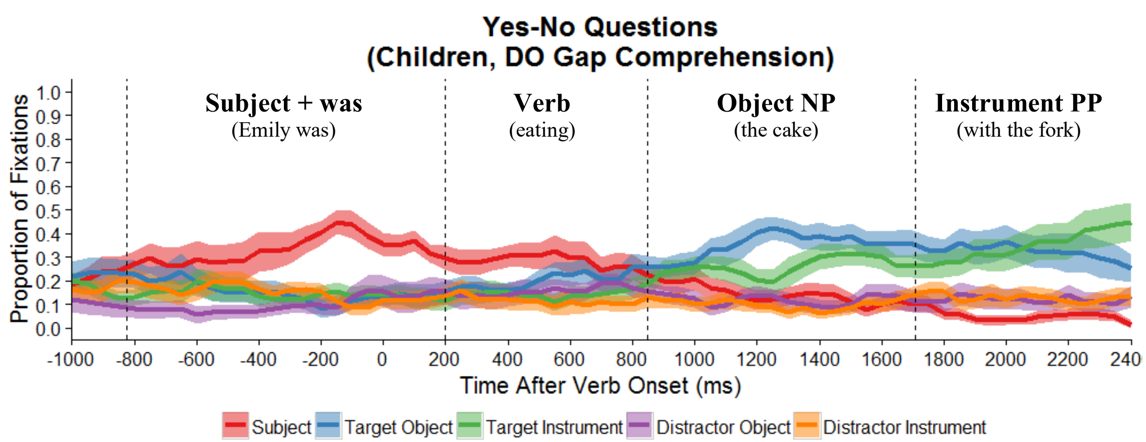



Figure 25. Proportion of fixations to the displayed items in the *yes-no* condition for 5-year-olds in the DO gap comprehension group. Shaded areas indicate ±1 standard error.

For the PO gap comprehension group, the proportion of fixations on the images over time is shown in Figure 26 for *wh*-questions and Figure 27 for *yes-no* questions.

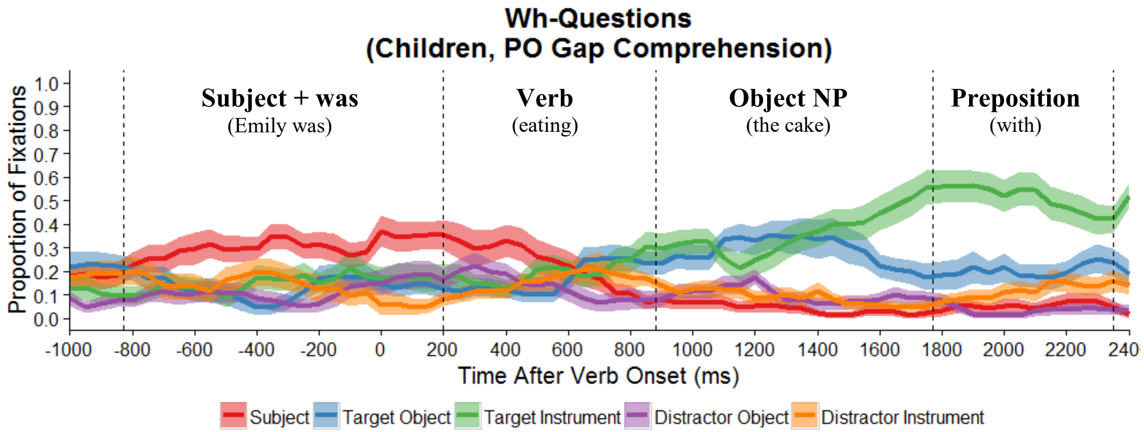



Figure 26. Proportion of fixations to the displayed items in the *wh*-condition for 5-year-olds in the PO gap comprehension group. Shaded areas indicate ±1 standard error.

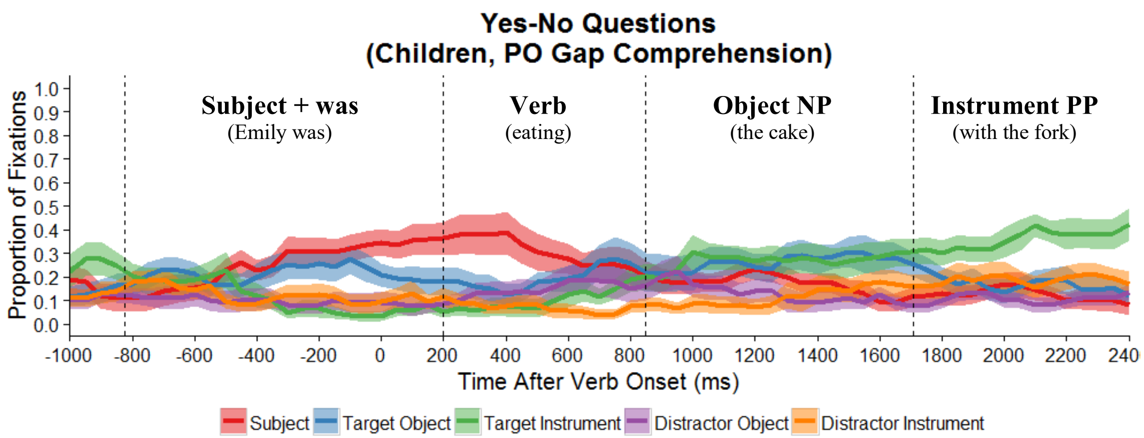



Figure 27. Proportion of fixations to the displayed items in the *yes-no* condition for 5-year-olds in the PO gap comprehension group. Shaded areas indicate ±1 standard error.

While there is some increase in the proportion of fixations on the target object (e.g., *cake*) during the verb region, these time course figures do not reveal any noticeable difference between the question type or comprehension group conditions. To examine this further, the fixations on the target object in this region were extracted and are plotted in Figure 28 by question type and comprehension group.

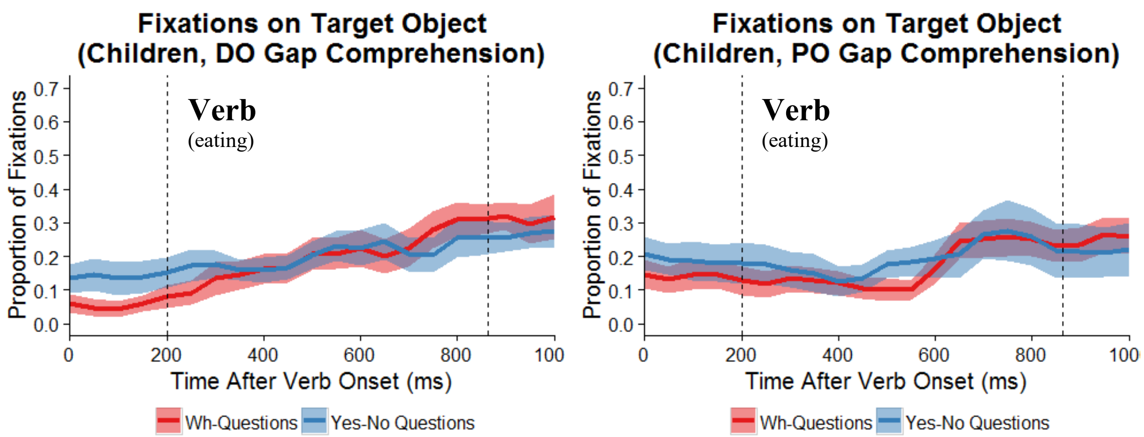



Figure 28. 5-year-old’s proportion of fixations on the target object in the verb region for both comprehension groups and question types. Shaded areas indicate ±1 standard error.

In the verb region, question type had a significant effect on the intercept ($\beta$ = -1.06, $SE$ = 0.26, $p$ < 0.001) and on the slope ($\beta$ = 1.70, $SE$ = 0.45, $p$ < 0.001). No other effects were significant. These results suggest that children were significantly more likely to be fixating on the target object at the onset of the verb region in *yes-no* questions and that the fixations on the target object of children in the DO gap comprehension group increased more rapidly than those in the PO gap comprehension group. Importantly, these effects are in opposite directions and essentially negate one another.

Although there were no significant interactions, planned pairwise comparisons can provide additional evidence for this interpretation. Both comprehension groups have an identical pattern of results: significant opposing effects of question type on the intercept (DO gap comprehension: $\beta$ = -0.80, $SE$ = 0.34, $p$ < 0.05; PO gap comprehension: $\beta$ = -1.25, $SE$ = 0.37, $p$ < 0.001) and on the slope (DO gap comprehension: $\beta$ = 1.52, $SE$ = 0.60, $p$ < 0.05; PO gap comprehension: $\beta$ = 1.75, $SE$ = 0.65, $p$ < 0.01). As there was no reliable difference in fixation pattern based on question type for either comprehension group, 5-year-olds were not actively filling the gap in the verb region in this experiment.

In the second region of interest, the object NP region, children in both comprehension groups increase their fixations on the target instrument (e.g., *fork*). This fixation data is isolated in Figure 29 by question type and comprehension group.

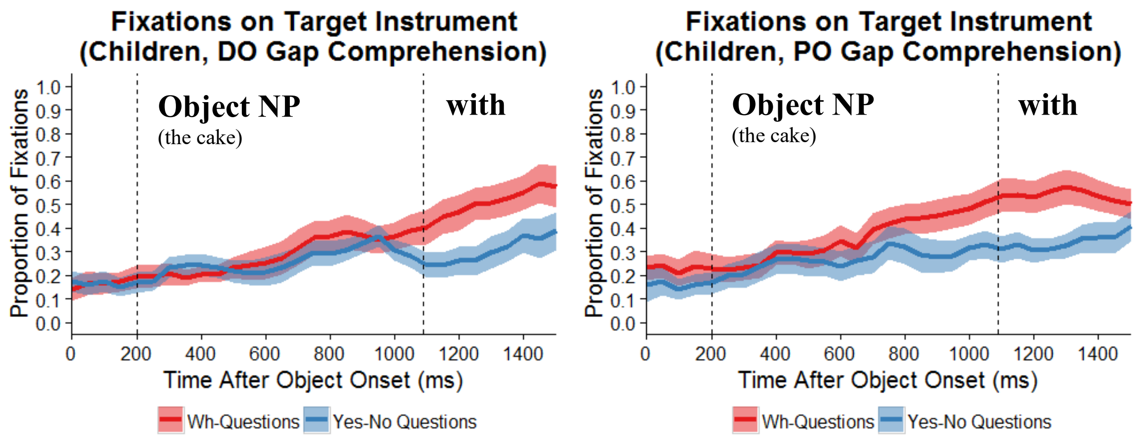



Figure 29. Isolation of the children's proportion of fixations on the target instrument in both question type conditions separated by comprehension group. Shaded areas indicate ±1 standard error.

The only significant effect in this region is of question type on the slope ($\beta = 0.65$, $SE = 0.32$, $p < 0.05$). Fixations on the target instrument increased more rapidly during *wh*-questions compared to *yes-no* questions. This result indicates that they were predicting a prepositional object gap during the object NP region. Overall, children in both comprehension groups patterned alike; they did not actively associate the filler with the verb, but they did predict a prepositional object gap in the object NP region.

*Comparison of adults and 5-year-olds.* Having analyzed the two age groups (adults vs. 5-year-olds) separately, these final overall analyses combine the age groups into a single model for each region of interest. In the verb region, both question type ($\beta = -0.55$, $SE = 0.28$, $p < 0.01$) and age group ($\beta = 1.07$, $SE = 0.42$, $p < 0.05$) have significant effects on the intercept. Participants in both age groups were more likely to be fixating on the target object at the onset of the verb in *yes-no* questions, but adults were more likely to be fixating on the target object at the onset of the verb in general.

Additionally, there was a significant interaction of question type and age group ($\beta$ = 0.96, *SE* = 0.37, $p < 0.01$) on the intercept. There was also a significant three-way interaction of question type, age group, and comprehension group ($\beta$ = -1.87, *SE* = 0.74, $p < 0.05$). Taken together, these interactions reflect the fact that children were more likely to be fixating on the target object in the verb region of *yes-no* questions regardless of comprehension group, but whether adults were more likely to be fixating on the target object in *wh*-questions versus *yes-no* questions depends on comprehension group. Adults in the DO gap comprehension group were more likely to fixate on the target object in *yes-no* questions, while the opposite was true for adults in the PO gap comprehension group.

On the slope, there was a significant effect of question type ($\beta$ = 1.05, *SE* = 0.32, $p < 0.01$). Participant's fixations on the target object increase more rapidly during the verb region of *wh*-questions compared to *yes-no* questions. The interaction of question type and age group also had a marginal effect on the slope ($\beta$ = -1.21, *SE* = 0.64, $p < 0.1$). This marginal interaction likely reflects the fact that children were not actively filling the direct object gap at the verb, while adults in the PO gap comprehension group were predicting the direct object gap at the onset of the verb and, thus, maintaining their fixations on the target object throughout the region.

In the object NP region, there were no significant effects on the intercept. However, question type had a significant effect on the slope ($\beta$ = 1.35, *SE* = 0.22, $p < 0.001$) such that fixations on the target instrument increased more quickly during *wh*-questions. Several interactions were also significant; the interaction of question type and age group had a significant effect on the slope ($\beta$ = 1.35, $SE$ = 0.44, $p$ < 0.01). The interaction of question type and comprehension group ($\beta$ = -1.11, $SE$ = 0.44, $p$ < 0.05) also had a significant effect on the slope. Both of these effects were the result of the difference in the strength of active filling of the prepositional object gap between the adults and the children. While adults in both comprehension groups clearly predicted the prepositional object gap during the object NP region, this prediction was less strong in children who comprehended DO gap questions during the picture completion task as evidenced by the late divergence in the fixations based on question type.

## 2.3 Discussion

The adults in this comprehension priming experiment generated unexpected results. Adults that comprehended prepositional object gaps maintained active gap filling during the eye tracking portion, while those that comprehended direct object gaps did not. These results were unexpected because adults demonstrated diminished active gap filling following exposure to prepositional object gaps in Experiment 3 (eye tracking during reading), not direct object gaps. The exact opposite was found in this experiment. Examining the eye tracking data more closely, however, reveals that the DO gap comprehension group was not fixating on the target object less during the verb region of *wh*-questions but rather that they were fixating on the target object more during the verb region of *yes-no* questions compared to the PO gap production group. Active gap filling is indicated by the difference between fixations on the target object in the two question types, so the increased fixations on the target object during *yes-no* questions for the DO gap comprehension group lead to the conclusion that they are not actively filling the direct object gap. Rather, I suggest that exposure to DO gap questions during the priming phase emphasized the direct object of events and lead to increased fixations on the direct object regardless of question condition.

This finding that direct objects in general are primed following direct object gap exposure may be related to findings that event structures can be primed (Bunger, Papafragou, & Trueswell, 2013). Bunger and colleagues examined whether participants' descriptions of motion events could be primed. In particular, they investigated whether the information included in a prime description of a motion event, e.g., information about the path, affected what information speakers chose to include in their subsequent descriptions. They found that participants were primed by the information included in the description of a motion event. They were more likely to mention the path of a target motion after comprehending a description of a motion event including this same information (e.g., *The zebra on the motorcycle entered the garage*). These findings indicate that the conceptual structure of the motion event was primed.

The priming of direct objects by direct object gap questions is consistent with priming of conceptual structure. In the picture completion task, the part of the event associated with the gap position was highlighted by the *wh*-questions. Participants in the DO gap comprehension group answered 25 questions about direct objects associated with instruments. This may have highlighted the role of the direct object in these object-instrument events (e.g., *drawing a cat with a crayon*), and thus primed interest in the object during processing. This object representation is primed independently of the particular structure being processed, so participants were just as interested in the target object during *yes-no* questions as during *wh*-questions.

The results for the 5-year-olds revealed that comprehension priming had no effect on their active gap filling behavior. Neither comprehension group predicted a direct object gap at the verb region of *wh*-questions, which is a similar result to that of Experiment 1 in which children comprehended filler-gap dependencies without priming. Thus, comprehension of filler-gap dependencies skewed toward direct object gaps is not sufficient to trigger active gap filling in 5-year-olds. This is somewhat unsurprising given the results of the visual world eye tracking study in Experiment 1 and the corpus analysis in Experiment 2. Children in Experiment 1 did not predict a direct object gap at the verb despite the distribution of gap positions in their input, which was strongly skewed toward direct object gaps as revealed by the corpus analysis in Experiment 2.

While these results suggest that comprehension priming is not a sufficient learning mechanism for adult-like filler-gap dependency processing, it is possible that the lack of priming is the result of methodological limitations. First, children may need more than 25 trials worth of exposure to learn about the distribution of gap positions. Savage et al.'s (2006) study, however, demonstrated immediate priming of the passive after just 5 primes when the verb used in the prime varied. Also, children in this study that demonstrated priming effects after a month had only been exposed to a total of 20 passive sentences across three experimental sessions.

It is also possible the lexical items used in the comprehension primes were not sufficiently variable to lead to abstract priming of gap positions. Priming in children has been found to be stronger with more varied input (Savage et al., 2006). While the verb was not identical across all 25 primes in the current study, only five verbs were used, and these verbs were repeated across primes associated with a single trial in the picture completion task. Were the verbs more varied, e.g., 25 different verbs, children may have been able to abstract away from the gap positions associated with a particular verb to the distribution of gap positions across individual lexical information.

Alternatively, the lack of priming may be due to an inability to transfer learning from one environment to another. The priming phase and test phase were presented as individual studies, rather than as a single experiment, although they did both take place within the same room. While information learned in one environment should transfer to another, it is possible that 5-year-olds were not able to generalize what they learned about gap positions from the picture completion task, e.g., that direct object gaps are common and should be expected in future *wh*-questions, to the visual world eye tracking experiment. This explanation is in line with the findings from Experiment 5 (sentence recognition and eye tracking during reading) that adults do not transfer distributional information from one experimental context to another.

## 3 Experiment 7 – Production priming

Though comprehension priming in Experiment 6 did not trigger active gap filling in 5-year-olds, it is possible that production priming could be more successful. Generally, production priming has been found to be more robust than comprehension priming (see Pickering & Ferreira, 2008 for a review). This suggests that priming from the picture completion task to the visual world eye tracking study may be stronger if children produce rather than comprehend *wh*-questions.

Also, there is recent work that suggests that production mechanisms are casually responsible for incremental comprehension (Pickering & Garrod, 2007, 2013; see also Federmeier, 2007). In particular, Pickering and Garrod (2013) propose a forward model of language production and comprehension. During comprehension, listeners predict upcoming language (at all levels) based on their previous experience comprehending sentences and based on their knowledge of the kind of utterance the speaker might produce. This later source of information for prediction crucially relies on the production system. Pickering and Garrod suggest that comprehenders covertly imitate the expected production using their own production system and that this covert imitation drives the predictions that, in turn, facilitate comprehension. Thus, production, or at least the ability to covertly imitate an utterance using one's production system, is the basis for syntactic predictions. Given this theory, children's production system could have a greater effect on the development of their syntactic predictions than their comprehension system. Experiment 7 attempts to prime the expectation of a direct object gap (i.e., active gap filling) by eliciting production of that structure.

Previous studies have shown that children as young as 2-years-old produce both subject and object *wh*-questions (Stromswold, 1995), so there is little concern that the children at the target age (5-years-old) will be able to produce questions with direct object gaps. Children's production of prepositional object gap questions, however, had not been previously examined and neither had the distribution of gap positions in children's questions. The former is critical to ensure that 5-year-olds would be capable of producing prepositional object gap questions in this experiment. The latter is important for testing the probabilistic parsing hypothesis for active gap filling. Both of these questions were addressed in the large corpus analysis in Chapter 2 (Experiment 2, see Section 3.2.3). The distribution of gap positions in children's productions mirrored the distribution in their input (from child-directed speech) and adult distribution.

Between 75% and 80% of the gap positions in children's productions were in the direct object position, while only 15-20% were in the prepositional object position. This bias is again consistent with a probabilistic account of active gap filling. Direct object gaps should be predicted because children produce them often and, therefore, they are the most probable gap position. Thus, priming of active gap filling may be possible by having children produce filler-gap dependencies with direct object gaps.

## 3.1 Method

### 3.1.1 Participants

Thirty-two English speaking children between the ages of 4;11 and 6;1 (mean age = 5;6; 21 females) participated in the study. These children were recruited from the communities surrounding Johns Hopkins University and the greater Baltimore area.

As a comparison group, 32 adult native speakers were recruited from the undergraduate population at Johns Hopkins University and received course credit for their participation. Two additional adult participants were tested but their data was excluded from analyses due to technical problems ($n = 2$).

### 3.1.2 Materials

#### *3.1.2.1 Picture completion task*

The materials for this task were identical to those used in the picture completion task in Experiment 6 (see Section 2.1.2.1). Children were assigned to one of two production groups: DO gap production (N = 16; mean age = 5;6) or PO gap production (N = 16; mean age = 5;6). Because the confederate experimenter asked the *where* questions in this experiment, they were more structured than those produced by the children in Experiment

6. Based on the child's assigned production group, the confederate experimenter asked one of two *where* questions, e.g., (4).

(4) a. Where was the girl drawing with the pencil?
    b. Where was the girl drawing the house?

The experimenter always included the part of the event that the child did not ask about in her questions, i.e., she included the instrument when the child asked direct object questions (4a), and she included the object when the child asked prepositional object questions (4b).

#### *3.1.2.2 Visual world eye tracking*

The eye tracking materials used in this study were identical to those used in Experiment 1, which were also used in Experiment 6 (see Section 2.1.2.2 for a brief summary).

### 3.1.3 Procedure

#### *3.1.3.1 Picture completion task*

The procedure for the picture completion task in this experiment was very similar to that from Experiment 6 except the roles were reversed. The 5-year-olds asked the DO gap or PO gap *what* questions first, and the confederate experimenter asked the questions about the location of events (i.e., the *where* questions) second. Also, after the confederate experimenter answered each of the child's questions, the organizing experimenter handed the child the associated sticker.

In this experiment, the organizing experimenter insisted that the child use the demonstrated verb to maintain uniformity across utterances. Thus, the practice page served an additional purpose; the organizing experimenter used it to demonstrate the target *wh*-questions (e.g., DO gap: *What did the boy eat __ with the spoon?*, PO gap: *What did the boy eat the soup with __?*). At the beginning of each trial, the organizing experimenter described the locations and the partial events to the child using the associated verb (e.g., *the girl is drawing something with a pencil* or *the girl is drawing the house with something*). During the experimental trials, if the child attempted to use a different verb or had a lengthy pause before producing the verb, the organizing experimenter prompted the child by repeating the relevant verb. Otherwise, the procedure was identical to that from the picture completion task portion of Experiment 6 (see Section 2.1.3.1).

#### *3.1.3.2 Visual world eye tracking*

As in Experiment 6, the procedure for the visual world eye tracking phase of the study was identical to that from Experiment 1 (see Section 2.1.3.2 for a brief review).

### 3.1.4 Data Analysis

#### *3.1.4.1 Picture completion task*

Children's utterances were transcribed and coded for accuracy.

#### *3.1.4.2 Visual world eye tracking*

The analysis procedure for the visual world eye tracking study was identical to that from Experiment 6 (see Section 2.1.4.2). As in Experiment 1 and Experiment 6, trials during which participants fixated disproportionately on the blank areas of the screen were excluded. For the adults in this study, 25% or greater of their fixations were required to be on one of the five pictures; for the children, 30% was required.

As in Experiment 6, the empirical logit (Barr, 2008) was calculated for fixation data from the two analysis regions – the verb and object NP regions – aggregated into 50ms bins. In this experiment, linear mixed effect models were fit to age groups (adults and 5-year-olds) individually before conducting an overall analysis. These separate age group analyses had question type (*wh*- vs. *yes-no* questions), production group (DO gap vs. PO gap production), and time as fixed effects and random intercepts for participants and items. Planned pairwise comparisons within age group evaluated the effect of production group. The DO gap and PO gap production groups were isolated and individually fit to another linear mixed effect model with question type and time as fixed effects and random intercepts for participants and items. Finally, the overall linear mixed effect model evaluated the differences between the age groups. This model used question type, production group, and age group (adults vs. children) as fixed effects with random intercepts for participants and items.

## 3.2 Results

### 3.2.1 Picture completion task

Children's production errors were of several types: usage of the wrong verb (e.g., *color* instead of *draw*), reference to the location instead of the missing object or instrument (e.g., *What was the girl collecting by the rocks?*), and description of the event using an adjunct clause headed by *when*. Alternate verb errors were further divided into questions with *using* and questions with other, unattested verbs because many children used the verb *using* instead of the demonstrated verb (e.g., *What was the girl using with the fire?*). An example of a production with an adjunct clause is given in (5).

(5) What was the girl collecting when she had a basket?

An additional error type was unique to the PO gap production group. Some children produce questions like (6a) when attempting to produce PO gap questions. In these errors, the object is produced as the complement of the preposition (intended meaning: *What is the boy washing the dog with?*).

(6) a. What is the boy washing with the dog?
b. What was the girl cooking with the egg with?

The organizing experimenter corrected the 5-year-olds when they produced this structure, usually by demonstrating the correct structure, e.g., *the dog with*, which sometimes led children to repeat the preposition both before and after the direct object (6b). Both error types were considered use of an object as the PP complement. Table 29 summarizes the average proportion of all of these errors by error type and production group.

Table 29. Average proportion of five-year-old's errors in producing the target questions by error type and production group. Standard errors are in parentheses.

<table>
<tr><th colspan="2"></th><th colspan="2">Production Group</th></tr>
<tr><th colspan="2">Error Type</th><th>DO Gap</th><th>PO Gap</th></tr>
<tr><td rowspan="2">Alternate verb</td><td>using</td><td>0.02 (0.02)</td><td>0.07 (0.03)</td></tr>
<tr><td>other</td><td>0.10 (0.02)</td><td>0.12 (0.03)</td></tr>
<tr><td colspan="2">Location instead of object / instrument</td><td>0.04 (0.01)</td><td>0.02 (0.01)</td></tr>
<tr><td colspan="2">Adjunct clause (5)</td><td>0.09 (0.03)</td><td>0.01 (0.005)</td></tr>
<tr><td colspan="2">Object as complement of the PP (6)</td><td>0 (0)</td><td>0.24 (0.08)</td></tr>
<tr><td colspan="2">Correct on first attempt</td><td>0.75 (0.03)</td><td>0.54 (0.09)</td></tr>
</table>

Children in the DO gap production group were good at utilizing the correct structure (*What was the girl/boy [verb]ing with the [instrument]?*). They were correct on the first attempt 75% of the time. When corrected, it was usually because they did not use the demonstrated verb (12% of errors), and they were able to produce the correct structure within 3 attempts. Children in the PO gap production group, on the other hand, had much more difficulty utilizing the demonstrated structure (*What was the girl/boy [verb]ing the [object] with?*). They were correct on the first attempt only 54% of the time. Although the structure was demonstrated during the practice session and repeated as necessary throughout by the organizing experimenter, some children were generally unable to produce it correctly. When they were unsuccessful, they usually repeated the preposition twice (*What was the girl/boy [verb]ing* with *the [object] with?*).

Children in the DO gap production group averaged 7.4 errors (*SE* = 1.2), while those in the PO gap production group averaged over 16 errors (mean = 16.7, *SE* = 4.0). Each child in the DO gap production group made a minimum of 2 errors, but no one made more than 15 errors. The median number of errors was seven. In addition to making more errors overall, many of the children in the PO gap production group made more errors individually. While one 5-year-old in this group made no errors at all, seven made more than 20 errors. In this group, the median number of errors was twelve.

The most common error type for 5-year-olds in the DO gap production group was use of an alternate verb (57 errors, about 54% of the errors) followed by use of an adjunct clause, e.g., (5) (35 errors, 33% of the errors). Neither error type is particularly serious, however, and both are easily corrected by modeling of the verb (for alternate verb errors) or the structure of the instrument prepositional phrase (e.g., *with*…). Like the DO gap production group, the most common error type for the PO gap production group was the use of an alternative verb (129 errors, 46% of the errors). Unlike the DO gap production group, however, the second most common error was use of the direct object as the PP complement, e.g., (6) (124 errors, about 44% of the errors), and this error only occurred in the PO gap production group. Four children only made errors of this second type (ranging from 1 to 24 errors), and four children (with some overlap) made 15 or more of this type of error. This error type and children's general difficulty producing PO gap structures will be critical for interpreting the visual world eye tracking data, and I will return to it in the discussion.

### 3.2.2 Visual world eye tracking

#### *3.2.2.1 Question accuracy*

Adults answered 99% of the questions correctly; thirty of the adults were 100% accurate, while the remaining two adults answered a single question incorrectly. One of these incorrect answers was to a target question and was excluded from the analysis (1 out of 320, < 1%). Five-year-olds had a mean accuracy of 97%, and no child was less than 85% accurate (i.e., no more than 3 questions answered incorrectly). Two of these incorrect answers were to target questions, so these trials were excluded from the analysis (2 out of 320, < 1%).

#### *3.2.2.2 Eye tracking data*

*Adults.* Nineteen of the 320 target trials (~6%) were excluded for failure to surpass the 40% criterion for minimum duration of fixations on the pictures. Including the trial excluded for inaccuracy, a total of 20 adult target trials (6%) were excluded.

As in Experiments 1 and 6, adults fixate on the pictures as they are named (see also Altmann & Kamide, 1999; Sussman & Sedivy, 2003). Because production group was a between participants factor, the time course data for the DO gap and PO gap groups are presented separately. Figure 30 presents the adult DO gap production group's fixation proportions during the *wh*-condition, while Figure 31 presents the same group's fixation proportions during the *yes-no* condition.

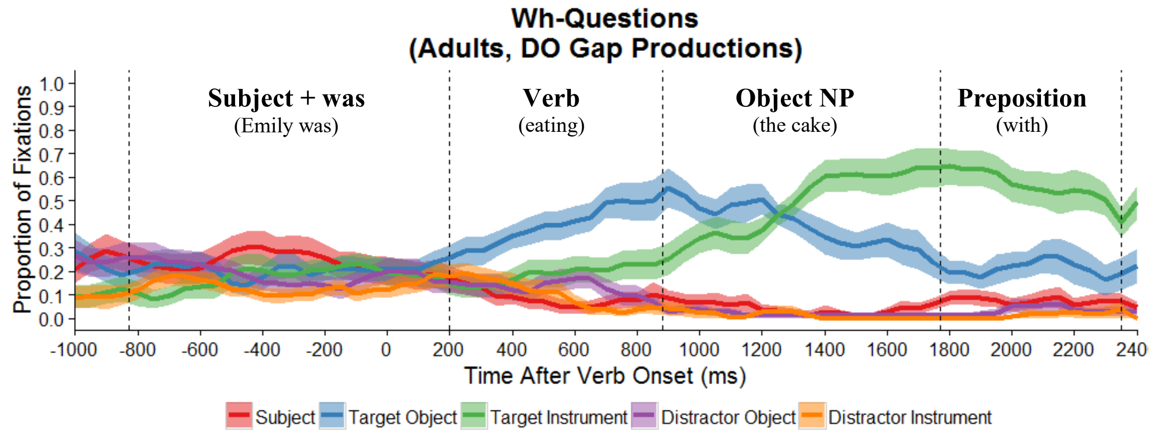



Figure 30. Proportion of fixations to the displayed items in the *wh*-condition for adults in the DO gap production group. Shaded areas indicate ±1 standard error.

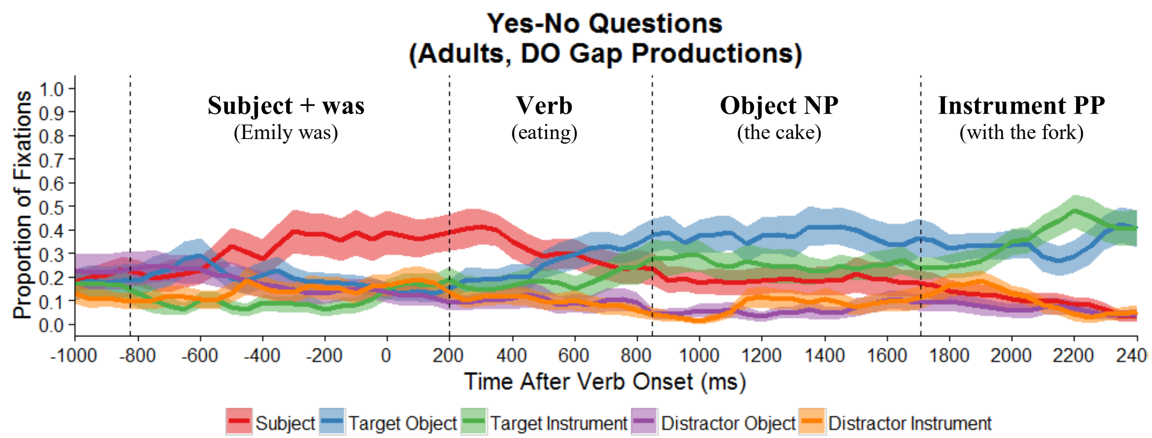



Figure 31. Proportion of fixations to the displayed items in the *yes-no* condition for adults in the DO gap production group. Shaded areas indicate ±1 standard error.

Time course data for the adults in the PO gap production group is given in Figure 32 (*wh*-question condition) and Figure 33 (*yes-no* question condition).

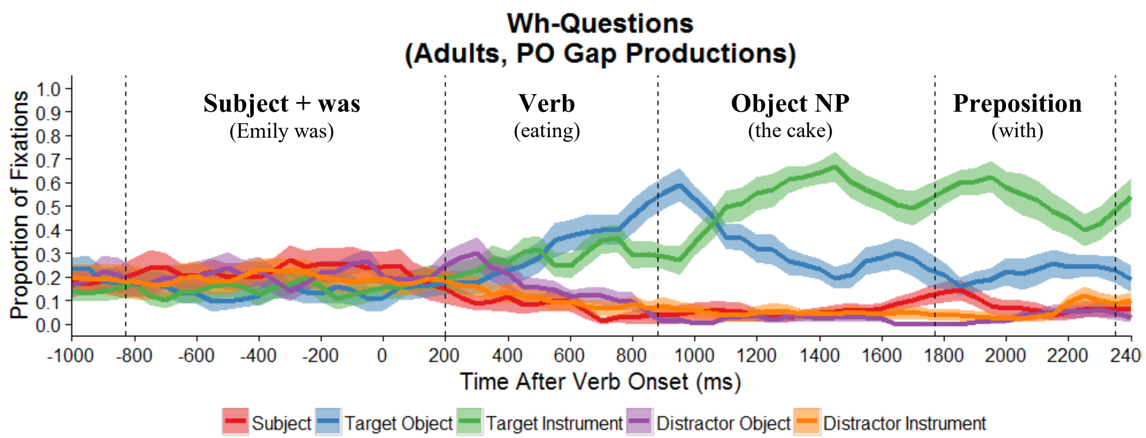



Figure 32. Proportion of fixations to the displayed items in the *wh*-condition for adults in the PO gap production group. Shaded areas indicate ±1 standard error.

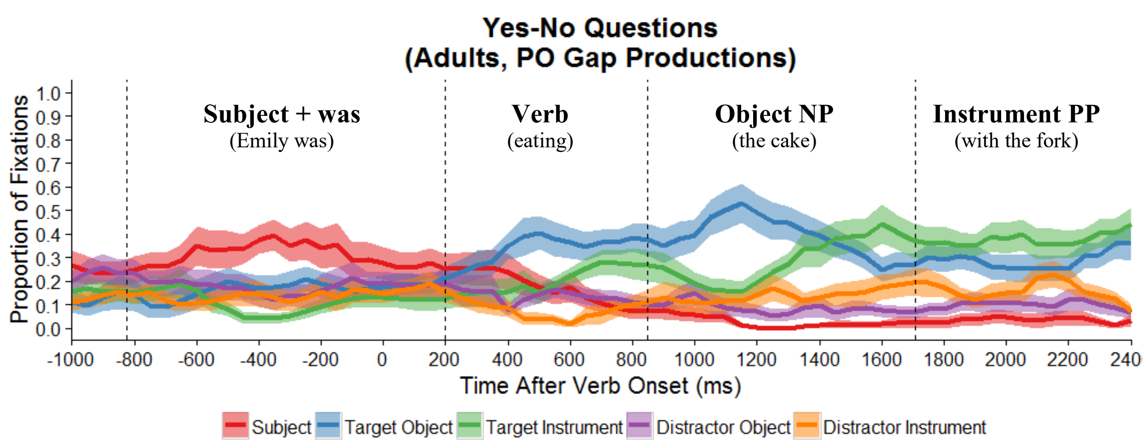



Figure 33. Proportion of fixations to the displayed items in the *yes-no* condition for adults in the PO gap production group. Shaded areas indicate ±1 standard error.

In both production groups, the fixations on the target object (e.g., *cake*) increased in the verb region of *wh*-questions (Figure 30 and Figure 32). In the object NP region of these questions, both production groups increase their fixations on the target instrument (e.g., *fork*). In the *yes-no* question condition for the DO gap production group (Figure 31), fixations on the target object also increased in the verb region, but this increase was not as steep as it was in the *wh*-condition. Conversely for the PO gap production group, fixations on the target object increased in the verb region approximately the same amount in both the *wh*-question condition (Figure 32) and the *yes-no* question condition (Figure

33). Figure 34 isolates the fixations on the target object in both question type conditions separated by production group.

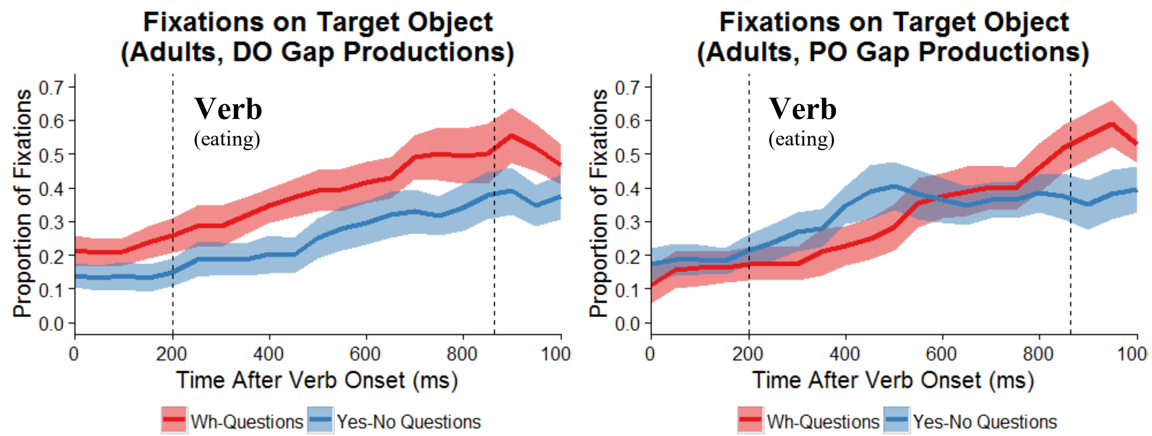



Figure 34. Adults' proportion of fixations on the target object in the verb region for both production groups and question types. Shaded areas indicate ±1 standard error.

In the verb region, the only significant effect on the intercept was an interaction of question type and production group ($\beta$ = 2.31, *SE* = 0.52, $p < 0.001$), which suggests that adults in the DO gap production group had a greater difference in question type at the intercept compared to the PO gap production group. For the slope terms, there was a significant effect of question type ($\beta$ = 0.98, *SE* = 0.45, $p < 0.05$). The slope for the *wh*-questions was significantly greater than that for the *yes-no* questions. Additionally, there was a significant interaction of production group and question type on slope ($\beta$ = -2.58, *SE* = 0.90, $p < 0.01$).

Planned pairwise comparisons for the DO gap production group demonstrated a significant difference at the intercept for the two question types ($\beta$ = 0.97, *SE* = 0.37, $p <$ 0.01), but no effects on the slope. Adults that produced DO gaps were more likely to be fixating on the target object at the beginning of the verb region during the *wh*-questions, but there was no difference in slope based on question type. These findings contrast with those from Experiment 1, where question type had a significant effect on the slope and not on the intercept. This suggests that the effect of producing DO gap questions was to speed up adults' predictions; the separation in fixation patterns happened closer to 150ms after the onset of the verb, rather than 200ms.

Planned pairwise comparisons for the PO gap production group revealed opposing significant effects of question type on the intercept ($\beta$ = -1.31, $SE$ = 0.36, $p < 0.001$) and on the slope ($\beta$ = 2.18, $SE$ = 0.61, $p < 0.001$). The effect at the intercept suggests that adults that produced PO gaps were more likely to be fixating on the target object at the onset of the verb region in the *yes-no* condition. Conversely, the effect of question type on the slope indicates that fixations on the target object increased more rapidly in the *wh*-question condition. These effects essentially negate one another. Adults were more likely to already be fixating on the target object at the beginning of the verb region during *yes-no* questions, but their fixations on the target object increased more rapidly during *wh*-questions to close this gap so that fixations on the target object in both conditions were essentially the same.

In the object NP region, adults in both production groups increased their fixations on the target instrument during *wh*-questions. Figure 35 extracts the proportion of fixations on the target instrument (e.g., the fork) by question type and production group. Adults in both production groups have a greater number of fixations on the target instrument during *wh*-questions, and the fixations based on question type diverge approximately 200ms after the onset of the object NP region.

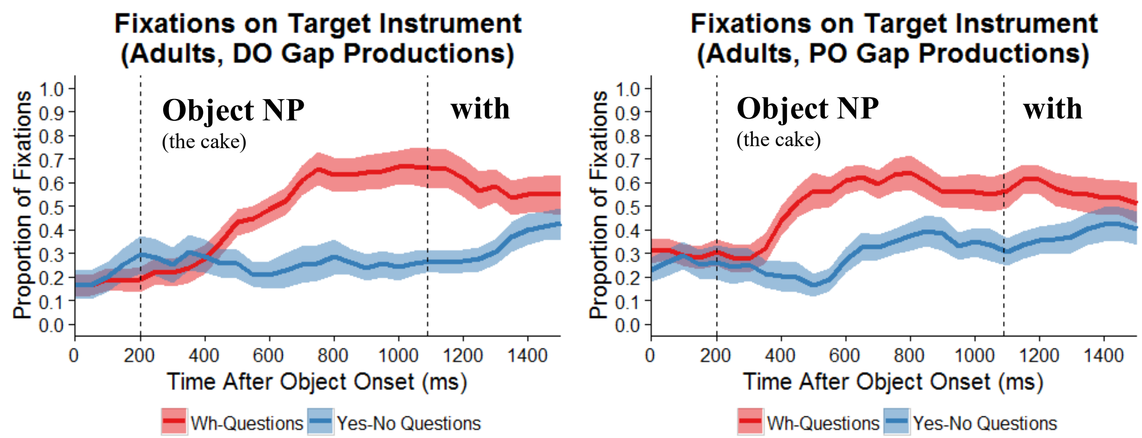



Figure 35. Isolation of the adults' proportion of fixations on the target instrument in both question type conditions separated by production group. Shaded areas indicate ±1 standard error.

There was a significant interaction of question type and production group on the intercept ($\beta$ = -2.07, $SE$ = 0.41, $p$ < 0.001). The DO gap production group was more likely to be fixating on the target object at the intercept in the *yes-no* question condition, while the PO gap production group was more likely to be fixating on the target object at the onset of the region during *wh*-questions. There were also two significant effects on the slope. Question type had a significant effect on the slope ($\beta$ = 1.74, $SE$ = 0.30, $p$ < 0.001) such that the slope was greater for *wh*-questions. Additionally, there was a significant interaction of question type and production group on the slope ($\beta$ = 3.19, $SE$ = 0.60, $p$ < 0.001). The slope for *wh*-questions was greater in the DO gap production group compared to the PO gap production group.

These interpretations are confirmed by the planned pairwise comparisons. For the DO gap production group, there was a significant effect of question type on both the intercept ($\beta$ = -1.00, $SE$ = 0.29, $p$ < 0.001) and the slope ($\beta$ = 3.28, $SE$ = 0.42, $p$ < 0.001). While participants were more likely to be fixating on the target instrument at the onset of the object NP region during *yes-no* questions, this initial preference was overcome by the significantly greater slope for *wh*-questions. Conversely, for the PO gap production group, there was only a significant effect of question type on the intercept ($\beta = 1.05$, $SE = 0.29$, $p < 0.001$). The effect of question type on the slope was not significant ($\beta = 0.08$, $SE = 0.43$, $p > 0.1$).

Overall, adults' active association of the filler with the verb was accelerated by exposure to DO gap questions. Fixations on the target object during *wh*-questions diverged less than 200ms after the verb onset. Conversely, adults in the PO gap production group did not demonstrate active gap filling at the verb. Both production groups, however, predicted prepositional object gaps during the object NP region.

*5-year-olds*. Fourteen of the 320 target trials (~4%) were excluded for not surpassing the 35% criterion for minimum duration of fixations on the pictures. Including the two trials excluded for inaccuracy, a total of 16 of children's target trials were excluded (5%).

Similar to the adults and the children in Experiments 1 and 6, 5-year-olds in this experiment fixate on the pictures as they are named (see also Altmann & Kamide, 1999; Sussman & Sedivy, 2003). Figure 36 presents the 5-year-old DO gap production group's fixation proportions during the *wh*-condition, while Figure 37 presents the same group's fixation proportions during the *yes-no* condition.

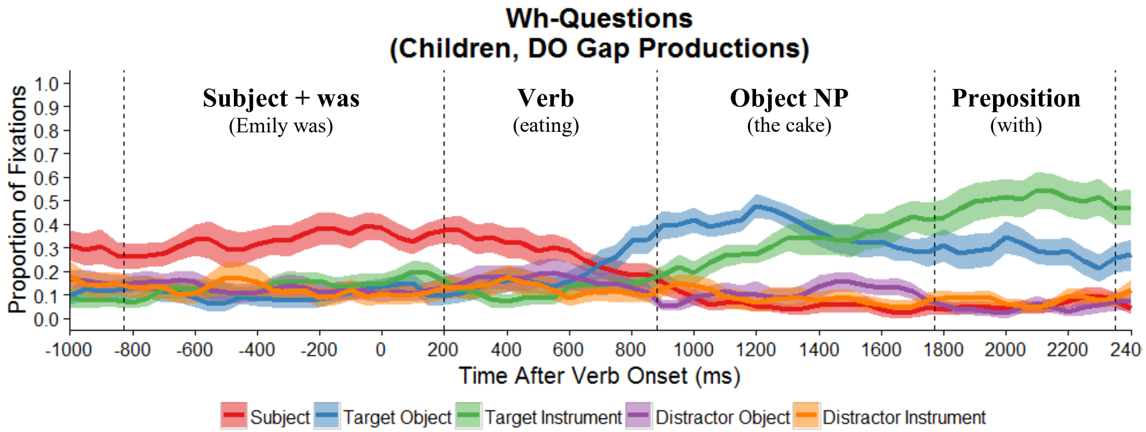



Figure 36. Proportion of fixations to the displayed items in the *wh*-condition for 5-year-olds in the DO gap production group. Shaded areas indicate ±1 standard error.

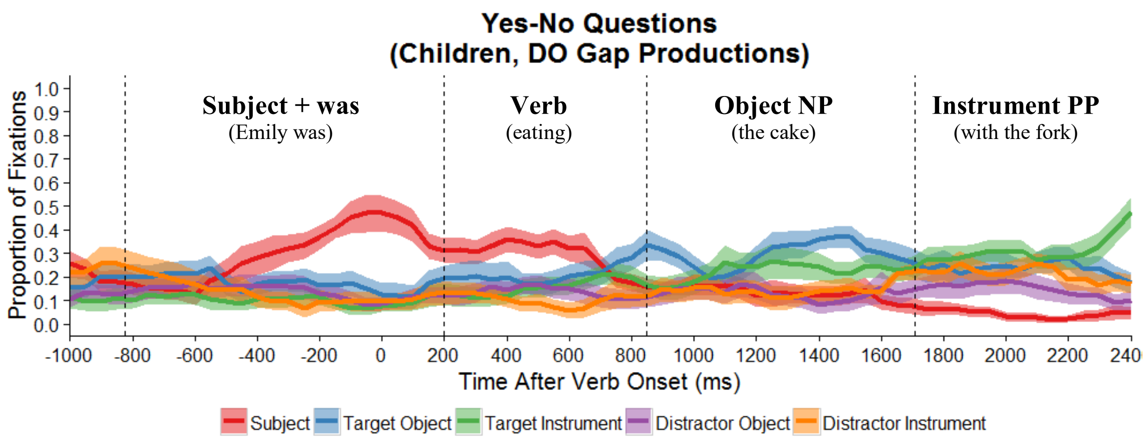



Figure 37. Proportion of fixations to the displayed items in the *yes-no* condition for 5-year-olds in the DO gap production group. Shaded areas indicate ±1 standard error.

The time course data for the 5-year-olds in the PO gap production group is presented in Figure 38 (*wh*-questions) and Figure 39 (*yes-no* questions).

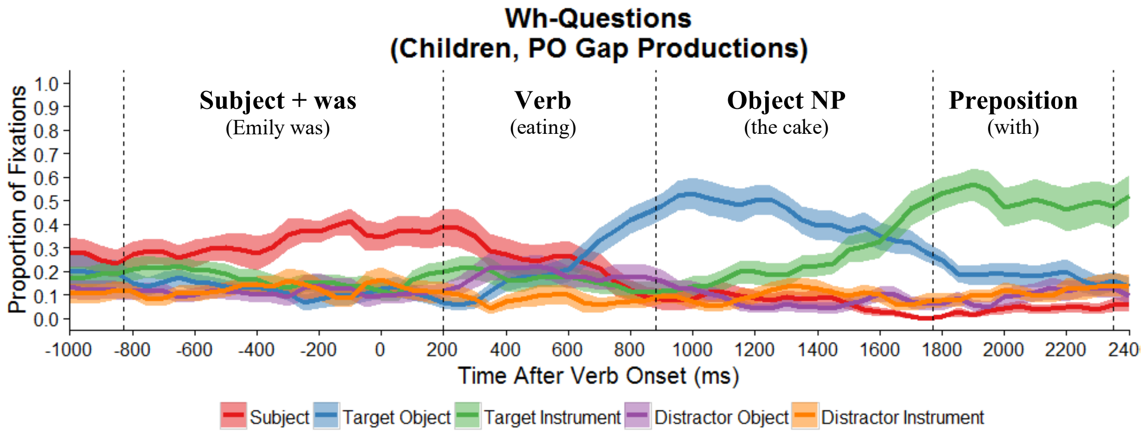



Figure 38. Proportion of fixations to the displayed items in the *wh*-condition for 5-year-olds in the PO gap production group. Shaded areas indicate ±1 standard error.

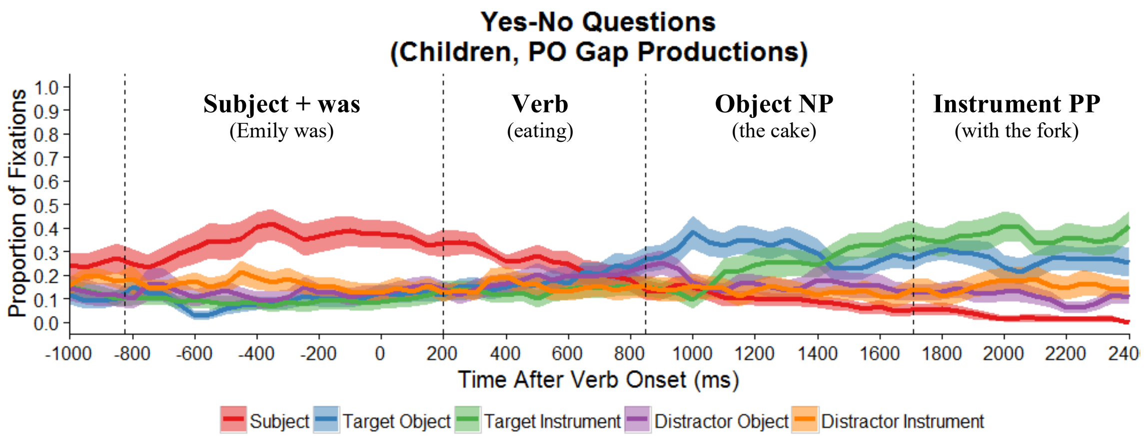



Figure 39. Proportion of fixations to the displayed items in the *yes-no* condition for 5-year-olds in the PO gap production group. Shaded areas indicate ±1 standard error.

In the verb region, fixations on the target object (e.g., *cake*) greatly increased in the *wh*-questions of the group that produced PO gaps (Figure 38). In all other combinations of conditions – both question types in the DO gap production group (Figure 36 and Figure 37) and *yes-no* questions in the PO gap production group (Figure 39) – fixations on the target object only slightly increased in the verb region. Figure 40 isolates the fixations on the target object in both question type conditions separated by production group.

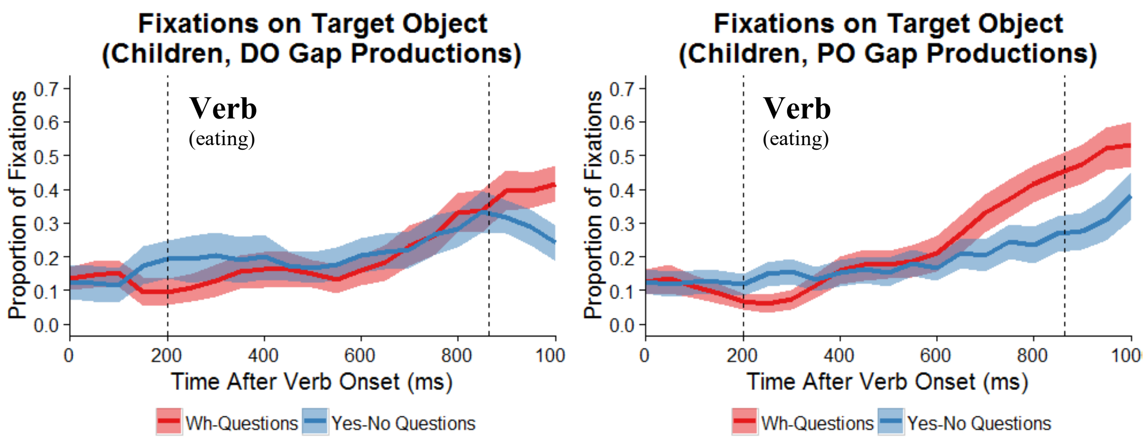



Figure 40. 5-year-old's proportion of fixations on the target object in the verb region for both production groups and question types. Shaded areas indicate ±1 standard error.

In the verb region, question type had a significant effect on the intercept ($\beta$ = -0.81, $SE$ = 0.24, $p < 0.001$) and the slope ($\beta$ = 1.61, $SE$ = 0.42, $p < 0.001$). There were no significant effects of production group, nor any significant interactions with question type on either the intercept ($\beta$ = 0.27, $SE$ = 0.48, $p > 0.1$) or the slope ($\beta$ = -1.04, $SE$ = 0.84, $p > 0.1$). Planned pairwise comparisons, however, reveal differences between the two production groups. For the DO gap production group, question type had a significant effect of on the intercept ($\beta$ = -0.72, $SE$ = 0.35, $p < 0.05$) and a marginal effect on the slope ($\beta$ = 1.16, $SE$ = 0.60, $p$ = 0.05). These effects are in opposite directions, and essentially negate one another. The effect on the intercept suggests that 5-year-olds in the DO gap production group were more likely to be fixating on the target object at the onset of the verb in the *yes-no* question condition, while the slope was greater in the *wh*-question condition.

In contrast, question type had a significant effect on the intercept ($\beta$ = -0.83, $SE$ = 0.33, $p < 0.05$) and on the slope ($\beta$ = 1.93, $SE$ = 0.58, $p < 0.001$) for the PO gap production group. While these effects are also in opposite directions, the significance of the effect of question type on the slope reflects the fact that participants that produced PO gaps increase their fixations on the target object in the last 250ms of the verb region of *wh*-questions. Unlike in the DO gap production group, the slope term overcomes the initial preference to fixate on the target object in the *yes-no* questions rather than just negating that preference.

Moving on to the second region of interest, both production groups increase their fixations on the target instrument (e.g., *fork*) in the object NP region of *wh*-questions (Figure 36 and Figure 38). Five-year-old's fixations on the target instrument during the object NP region are displayed in Figure 41.

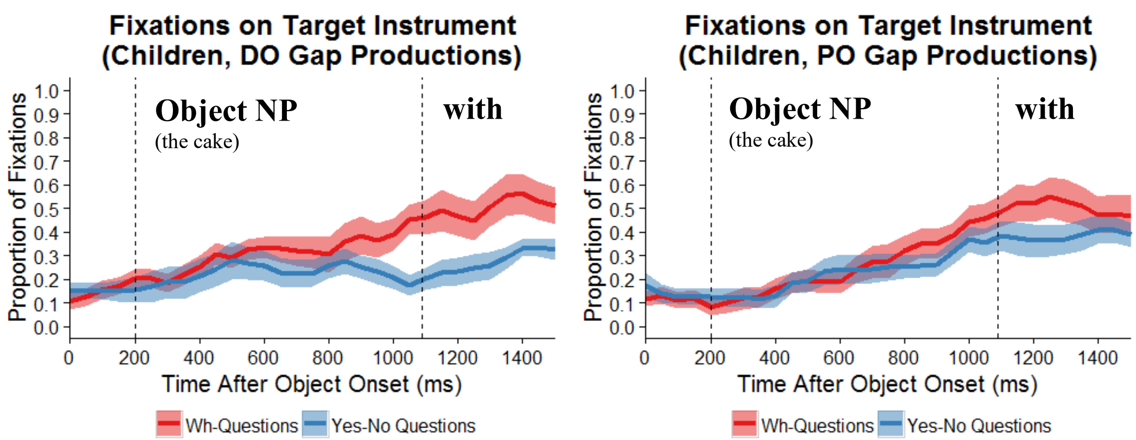



Figure 41. Isolation of the children's proportion of fixations on the target instrument in both question type conditions separated by production group. Shaded areas indicate ±1 standard error.

Only production group had a significant effect on the intercept ($\beta$ = 1.20, *SE* = 0.48, $p < 0.05$). Children who produced DO gap questions were more likely to be fixating on the target instrument at the onset of the object NP region compared to those who produced PO gap questions. Both question type and production group had a significant effect on the slope (question type: $\beta$ = 1.02, *SE* = 0.30, $p < 0.001$; production group: $\beta$ = -1.45, *SE* = 0.69, $p < 0.05$). Fixations on the target instrument increased more quickly during the object NP region of *wh*-questions compared to *yes-no* questions. Also, fixations on the target instrument increased more quickly over time for children that produced PO gap questions compared to DO gap questions. Planned pairwise comparisons reveal that question type had a significant effect only on the slope for both the DO gap production group ($\beta = 0.99$, $SE = 0.43$, $p < 0.05$) and the PO gap production group ($\beta = 1.09$, $SE = 0.41$, $p < 0.01$). In both cases, fixations increased more rapidly on the target instrument during *wh*-questions compared to *yes-no* questions.

Taken together, these results suggest that children in both production groups actively associated the filler with the prepositional object gap during the object NP region (although this gap prediction is qualitatively larger for the DO gap production group). However, only the children that produced PO gap questions demonstrate active gap filling at the verb. Reasons for why PO gap and not DO gap production primed active gap filling will be explored in the discussion below.

*Comparison of adults and 5-year-olds.* As a final analysis, an overall analysis was conducted on the data from both adults and 5-year-olds in both the verb and object NP regions. On the intercept of the verb region, there was a significant effect of question type ($\beta = -0.49$, $SE = 0.18$, $p < 0.01$) and a marginal effect of age group ($\beta = 0.69$, $SE = 0.40$, $p < 0.1$). Participants were more likely to be looking at the target object at the onset of the verb region during *yes-no* questions. Also, adults were marginally more likely than the 5-year-olds to be looking at the target object at the onset of the region.

Additionally, there was a significant two-way interaction of question type and production group on the intercept ($\beta = 1.28$, $SE = 0.36$, $p < 0.001$), as well as a significant three-way interaction of question type, production group, & age group ($\beta = 2.14$, $SE = 0.71$, $p < 0.01$). The two-way interaction suggests that participants in the DO gap production group were more likely to be fixating on the target object at the onset of the verb region, but the three-way interaction suggests this effect is tempered by age group as well: adults were more likely than children to be fixating on the target object at the onset of the verb in *wh*-questions. These significant interactions reflect the fact that adults in the DO gap production group (and not the PO gap production group) demonstrated active gap filling at the verb, while it was children in the *PO gap production group* that demonstrated active interpretation of the filler as the direct object of the verb.

On the slope, there was a significant effect of question type ($\beta$ = 1.22, *SE* = 0.31, $p < 0.001$); fixations on the target object increased more quickly during the verb region of *wh*-questions. Also, there was a significant interaction of question type and production group ($\beta$ = -1.70, *SE* = 0.62, $p < 0.01$), which suggests that the slope for each question type varied based on the production group.

In the object NP region, age group had a significant effect on the intercept ($\beta$ = 0.74, *SE* = 0.34, $p < 0.05$) such that adults were more likely to be fixating on the target instrument at the onset of the region. Several interactions were also significant; the interaction of question type and production group had a significant effect on the intercept ($\beta$ = -0.75, *SE* = 0.29, $p < 0.01$), as did production group and age group ($\beta$ = -1.65, *SE* = 0.69, $p < 0.05$). There was also a significant three-way interaction of question type, production group, and age group ($\beta$ = -2.69, *SE* = 0.59, $p < 0.001$). These interactions reflect the individual age group results. While there was a significant effect of question type on the intercept for the children, there was no such effect for the adults.

Question type also had a significant effect on the slope ($\beta$ = 1.44, *SE* = 0.21, $p < 0.001$). Fixations on the target instrument during the object NP increased more rapidly during *wh*-questions. Like on the intercept, there were multiple significant interactions that affected the slope: the interaction of question type and production group ($\beta = 1.61$, $SE = 0.42$, $p < 0.001$) and production group and age group ($\beta = 1.90$, $SE = 0.93$, $p < 0.05$) were both significant. There was also a marginal interaction of question type and age group ($\beta = 0.79$, $SE = 0.42$, $p < 0.1$). Finally, there was a significant three-way interaction between question type, production group, and age group ($\beta = 3.57$, $SE = 0.85$, $p < 0.001$). These interactions are sensible given the age group results. While both adults and children predicted the prepositional object gap during the object NP region, children in the PO gap production group make a weaker prediction compared to children in the DO gap production group and adults in both groups.

## 3.3 Discussion

In this experiment, adults' real time comprehension processes underwent expected adaptation to the input distribution, which was similar to the adaptation effect that was reported in Experiment 3 (eye tracking during reading). Specifically, the group that produced prepositional object gaps during the priming phase ceased to demonstrate active gap filling at the verb during the eye tracking experiment. This suggests that the direct object gap prediction was diminished by the production of questions with a later post-verbal gap (i.e., a prepositional object gap). Additionally, the fixation data during the object NP region reveals that prediction was not just suppressed in general for the group the produced PO gaps (cf. Experiment 4). In this region, adults revealed their prepositional object gap predictions by fixating more on the target instrument during *wh*-questions. Thus, despite not making a gap prediction at the verb, the PO gap production group continues to predict a prepositional object gap after a direct object gap has been ruled out by the presence of an overt direct object.

The 5-year-olds' results, on the other hand, were unexpected because one gap position (prepositional object gaps) primed a different gap position (direct object gaps). While production of *wh*-questions did affect their active gap filling behavior, it was the group that produced prepositional object gaps rather than the group that produced direct object gaps that demonstrated active gap filling at the verb in the eye tracking portion of the study. This finding is contra the probabilistic parsing account of active gap filling; if the distribution of gaps in the input determines at which syntactic position gaps are predicted in real time, then the group that produces direct object gaps should predict direct object gaps when processing future utterances containing filler-gap dependencies.

In general, this pattern of results is difficult to reconcile with any of the theories of active gap filling or syntactic priming and adaptation reviewed thus far because no account predicts a facilitatory effect of exposure to prepositional object gaps. Consequently, I propose an alternative explanation that relies upon the difficulty children experienced in producing these questions. Particularly, children in the PO gap production group made significantly more errors ($t$ = -2.23, $p < 0.05$), many of which were a misuse of a direct object gap structure. Also, prepositional object gaps were far less frequent in children's spontaneous productions than direct object gaps (20.6% versus 79.4%).

I suggest that children's general abstract representation of filler-gap dependencies is primed by the processing effort required to produce the PO gap structure. Specifically, when producing *wh*-questions in the PO gap production group, many children seem to be utilizing a filler-gap dependency structure with a direct object gap as demonstrated by their errors in the use of the direct object as the complement of the PP (e.g., *What was the girl drawing with the cat?*), see (6). This error type suggests that direct object gaps are fundamentally easier to produce, which is supported by their frequency in children's input and spontaneous utterances. Given the infrequency of prepositional object gaps in children's input and spontaneous productions (see Experiment 2 in Chapter 2), it is possible that the production of these gaps requires children to activate the filler-gap dependency structure more strongly than the production of direct object gaps. A higher activation of a non-direct object gap like a prepositional object gap may be necessary to overcome children's strong preference for the direct object gap structure. This processing effort may, in turn, strengthen the general structure of these dependencies and draw attention to the fact that direct object gaps are particularly common in this structure. This realization, which is supported by the fact that children often mistakenly use a direct object gap structure in the PO gap production condition, may be sufficient to trigger active gap filling at the verb in the subsequent comprehension experiment.

It is important to note that, while there was evidence that 5-year-olds in the PO gap production group were actively predicting a direct object gap at the verb, this prediction only appears late in the region. Thus, while production priming may encourage active gap filling, it is not sufficient to trigger gap predictions at an adult-like speed during filler-gap dependency processing.

## 4 Overall Discussion

This chapter examined whether priming could be a mechanism for learning adult-like filler-gap dependency processing biases. Experiment 6 examined the effect of comprehension priming on active gap filling in 5-year-olds, while Experiment 7 attempted to trigger active gap filling with production priming. Comprehension priming had no detectable effect on children's active gap filling. On the other hand, production priming did trigger active gap filling, but only for those children who produced prepositional object gaps during the picture completion task. These results were surprising because it was PO gap production, not DO gap production, that primed direct object gap predictions. Thus, production of filler-gap dependencies with a variety of gap positions, i.e., not just the frequent direct object gap structure, may be a pre-requisite for the development of active gap filling in children.

These results raise an obvious question: why was production priming more successful than comprehension priming? In the production priming task, children are forced to use the filler-gap dependency structure for argument questions, whereas they only comprehend these structures in comprehension priming. Pickering and Garrod (2013; see also Federmeier, 2007; Pickering & Garrod, 2007) argue for a causal relationship between the production system and incremental processing. They propose that comprehenders covertly imitate the expected utterance using their own production system. In this way, prediction of upcoming linguistic information can be seen as a form of production. Thus, it is possible that production of filler-gap dependencies has a more direct effect on the predictive mechanisms than comprehension.

Additional evidence for the importance of production on incremental processing comes from a study on young children's anticipatory fixations at the verb (Mani & Huettig, 2012). In a preferential looking study, Mani and Huettig demonstrated that 2-year-olds can generate anticipatory fixations on plausible objects of semantically restrictive verbs (e.g., *cake* is a plausible object of *eat*) at the same speed as adults.

Crucially, this ability was correlated with productive vocabulary size. Children who produced more words were adult-like in the speed of their anticipatory fixations, while those who produced fewer words were slower to generate these looks. These findings suggest that production may play a causal role in children's ability to incrementally process incoming information.

This direct link between production and prediction provides an explanation for why production priming was more successful than comprehension priming. It does not, however, explain why it was the PO gap production group in which active gap filling was primed. In the following chapter, I propose an implementation of a gap filling mechanism that accounts for the priming of active gap filling by prepositional object gap productions. Contra a probabilistic parsing account in which gap predictions have a specific structural position (i.e., active gap filling is the result of a specific prediction for a direct object gap), I suggest that potential gap positions are evaluated successively. Thus, the production of prepositional object gaps primes the abstract connection between a filler and its gap and triggers this successive search. This proposal is discussed extensively in the following chapter.

# Chapter 5 – Conclusion

## 1 Overview

Long distance dependencies – particularly filler-gap dependencies – have played an important role in the psycholinguistic study of syntactic predictions. They have been used to demonstrate syntactic commitments prior to confirmatory bottom-up information. Because of this focus on establishing the existence of syntactic prediction, many mechanisms of active gap filling have been suggested (Aoshima et al., 2004; Boland, Tanenhaus, Garnsey, & Carlson, 1995; Fodor, 1978; Frazier, 1987; Omaki et al., 2015; Pickering & Barry, 1991 among others). However, existing findings from the adult sentence processing research have not led to a consensus on the mechanistic details of filler-gap dependency processing. What is the form of the predicted representation and how is it evaluated? This chapter compares two potential implementations of the structural predictions involved in filler-gap dependency processing, evaluates them in light of the adult and developmental findings presented in this dissertation, and suggests future directions.

The goal of this dissertation was to investigate the role of representations and adaptation on syntactic predictions during filler-gap dependency processing. In the pursuit of an implementation of these predictions, I utilized a mostly untapped source of processing data: development. To test the probabilistic parsing account of syntactic prediction, I both examined and manipulated the distribution of gap positions available to adults and children in their input. The remainder of this section summarizes the main empirical findings of this dissertation, and is followed by discussion of the conclusions that can be drawn from these findings.

## 1.1 Summary of empirical findings

Table 30 summarizes the seven experiments detailed in this dissertation and their main findings. The starting point of the investigation into the effect of language experience on syntactic predictions began by examining children's syntactic predictions during real time comprehension of filler-gap dependencies. Although studies using offline methodologies suggested that children, like adults, actively complete filler-gap dependencies at the verb (Lassotta et al., 2015; Love, 2007; Omaki et al., 2014), children's syntactic predictions had not previously been demonstrated. A visual world eye tracking study (Experiment 1) examined whether children generate a direct object gap prediction while processing *wh*-questions. Five- to seven-year-olds were told a story about a limited visual world environment containing two salient events. After each story, children were asked either a *wh*-question (1a) or a *yes-no* question (1b) about one of the events in the story.

(1) Can you tell me…
    a. *Wh-question:* …what Emily was eating the cake with __?
    b. *Yes-no question:* …if Emily was eating the cake with the fork?

Table 30. Summary of experiments and main findings.

| | Population | Methodology | Main findings |
|---|---|---|---|
| Exp 1 | 5- to 7-year-olds<br>Adult controls | Visual world eye tracking | Children do not reliably demonstrate active gap filling at the verb, while adults do. Both age groups predict a prepositional object gap in the object NP region. |
| Exp 2 | Child-directed speech<br>Child speech<br>Naturalistic adult speech | Corpus analysis | Input to both children and adults favors direct object gaps over prepositional object gaps (~75% direct object gaps versus ~25% prepositional object gaps). The distribution of gap positions in the *wh*-questions that children produce resembles that from their input. |
| Exp 3 | Adults | Eye tracking during reading (blocked adaptation) | Exposure to prepositional object gaps in the local input decreases direct object gap predictions. |
| Exp 4 | Adults | Eye tracking during reading (blocked adaptation) | Exposure to prepositional object gaps in the local input <u>does not</u> increase prepositional object gap predictions. |
| Exp 5 | Adults | *Pt 1:* Sentence recognition<br>*Pt 2:* Eye tracking during reading | Distributional information does not generalize from one study to another. Exposure to prepositional object gaps in part one <u>did not</u> decrease direct object gap predictions in part two. |
| Exp 6 | 5-year-olds<br>Adult controls | *Pt 1:* Picture completion (comprehension)<br>*Pt 2*: Visual world eye tracking | *Adults:* Comprehension of prepositional object gaps led to no change in active gap filling, while comprehension of direct object gaps led to increased interest in objects in general.<br>*Children:* Comprehension of prepositional object gaps did not mitigate active gap filling (i.e., direct object gaps were not predicted). |
| Exp 7 | 5-year-olds<br>Adult controls | *Pt 1:* Picture completion (production)<br>*Pt 2:* Visual world eye tracking | *Adults:* Production of prepositional object gaps decreased active prediction of a direct object gap at the verb.<br>*Children:* Production of prepositional object gaps <u>increased</u> direct object gap predictions at the verb. |

An adult control group demonstrated direct object gap predictions by generating anticipatory fixations during the verb region; their fixations on the target object (e.g., the cake) were significantly greater when a filler was present than when one was not. Conversely, children of all ages did not reliably anticipate a direct object gap during the verb region of *wh*-questions. There was no significant difference between their fixations on the target object during *wh*-questions versus *yes-no* questions in the verb region, and there was an inconsistent effect of question type on fixations on the target object during the object noun phrase region. Additionally, both adults and children made anticipatory fixations on the target instrument during the object NP region of *wh*-questions. Thus, while children did not reliably predict a direct object gap, they did actively predict a prepositional object gap.

Experiment 2 examined whether the children's unreliable direct object gap predictions reflected the distribution of gaps in their input. I calculated the distribution of gap positions in children's *wh*-question productions and in the filler-gap dependency input to adults and children from naturalistic corpora. This analysis revealed that direct object gaps are the most frequent for both adults and children, especially when compared directly with another post-verbal gap position (i.e., prepositional object gaps). Thus, children's predictive behavior in Experiment 1 is not the result of a non-adult-like experience with gap positions.

Although children's predictions do not seem to be driven by their language experience, it is possible that distributional expectations are nonetheless the cause of the adult-like active gap filling bias (i.e., prediction of a direct object gap). There is evidence from the adult sentence processing literature that recent language experience has an effect on predictive structure selection processes (e.g., Fine et al., 2013, 2010; Myslín & Levy, 2016). Fine et al. (2013) demonstrated that exposure to an improbable structure (e.g., reduced relatives) decreases the difficulty processing that structure in the future, and also increases processing difficulty on the initially more probable structure (e.g., main verbs). This suggests that language experience can have an effect on adult's predictive structural selection processes, and therefore it may also have an effect on their predictive structural building processes.

Chapter 3 (Experiments 3-5) explored this possibility through a series of related eye tracking during reading studies. In Experiment 3, a group of adult participants were exposed to less frequent (and therefore less probable) prepositional object gaps (2a).

(2) a. The suitcase **that** the stealthy, wanted thief stole <u>the precious jewels</u> from __ was full of sentimental items.
b. The suitcase **from which** the stealthy, wanted thief stole <u>the precious jewels</u> __ was full of sentimental items.

The processing of these sentences with filled direct object gaps (e.g., *the precious jewels* occupies the direct object position) was compared to that of sentences with an unambiguous prepositional object gap which was indicated by pied piping of the preposition (2b). A reading time slowdown on the direct object region of the filled direct object gap sentences compared to the pied piping sentences indicates that a direct object gap was predicted; the slowdown is the result of surprise that the direct object position is occupied by an overt NP. Two control groups who were exposed to direct object gaps or filler sentences demonstrated a filled gap effect on the direct object NP region. The group that was exposed to prepositional object gaps, however, did not slowdown on the direct object NP region. Thus, participants adapted to input favoring prepositional object gaps and tempered their direct object gap predictions accordingly.

Experiments 4 and 5 examined the scope of this syntactic adaptation effect. Experiment 4 examined whether the decreased direct object gap predictions discovered in Experiment 3 were accompanied by increased prepositional object gap predictions. To test this, I constructed novel filled prepositional object gap sentences (3a) with sentences containing an island as a control (3b).

(3) a. The suitcase that the stealthy, wanted thief stole __ from <u>the hotel room</u> contained precious jewels.
b. The suitcase that the stealthy, wanted thief **who** stole from <u>the hotel room</u> coveted __ contained precious jewels.

If participants predicted a prepositional object gap, they should be surprised by the presence of a noun phrase in the complement position of the prepositional phrase. In the island conditions, however, this noun phrase should not be surprising because a gap cannot occur within an island environment. For the group exposed to direct object gaps, no differences between non-island (3a) and island (3b) sentences were observed. Similarly, no differences between these sentence types were observed for participants exposed to prepositional object gaps. These findings suggest that while participants were tempering their direct object gap predictions based on the distribution of gap positions in their local language experience, they did not use that input distribution to shift their gap predictions to the prepositional object position.

Experiment 5, on the other hand, examined the generalizability of the distributional information; prepositional object gaps were presented within a sentence recognition study, while the test of syntactic adaptation effects remained within a separate eye tracking during reading study. Unlike the findings from Experiment 3, participants exposed to prepositional object gaps during the sentence recognition study did not temper their direct object gap predictions during the reading study. Thus, the adaptation effect may not be general, but rather constrained to cases where a certain structure is repeated within a single experimental context or modality.

While the effect of syntactic adaptation for adults was limited, children may be able to use their recent language experience to boost their syntactic expectations. In Chapter 4 (Experiments 6 and 7), I investigated whether it was possible to trigger 5-year-old's ability to actively predict direct object gaps by exposing them to concentrated filler-gap dependency input. Children participated in a novel picture completion task during which they comprehended *wh*-questions with either a direct object (4a) or prepositional object (4b) gap before completing the same question-after-story visual world eye tracking study from Experiment 1 (Experiment 6).

(4) a. What was the girl drawing __ with the crayon?
    b. What was the girl drawing the cat with __?

This experiment replicated Experiment 1; regardless of structure, exposure via comprehension of filler-gap dependencies did not affect children's (lack of) direct object gap predictions.

Finally, Experiment 7 replicated Experiment 6 except the picture completion task elicited *wh*-question productions from the 5-year-olds. The results of this experiment contrast with those of Experiment 6. Surprisingly, children who produced prepositional object gaps went on to predict direct object gaps during *wh*-question comprehension, while those who produced direct object gaps did not. The implications of this result are discussed at length below.

## 2 Implications for the predictive mechanisms

There are two critical developmental findings of this dissertation: 1) 5- to 7-year-olds did not actively associate the filler with the verb, despite having been exposed to input favoring direct object gaps (Experiments 1 and 2), and 2) active gap filling was triggered in 5-year-olds only after they produced prepositional object gaps (Experiments 6 and 7). Thus, an implementation of active gap filling must be able to account for these findings.

This section first reviews the probabilistic parsing account of gap prediction, which requires the generation of specific structural predictions, and evaluates it in light of the adult and developmental findings presented in this dissertation. According to the this account, syntactic predictions during filler-gap dependency processing are implemented via the prediction of a specific structure. In order to compute the probability of a particular gap position, the frequency of specific gap positions must be compared to one another. Thus, active gap filling occurs because a direct object gap is specifically predicted.

This dissertation presents a wealth of evidence against the specific structural prediction account, however, so this section continues by describing and evaluating an alternative implementation – successive gap evaluation. According to this implementation, active gap filling results from successive gap evaluation as new input arrives. As a preview, I argue that the successive gap evaluation account is the only one that can explain all of the critical results from this dissertation, especially the results of the production priming study (Experiment 7).

## 2.1 Specific structural prediction

The first implementation posits that syntactic prediction in filler-gap dependency processing is the result of a specific structural prediction of the gap position. In other words, active gap filling at the verb region is the result of a prediction that the gap will occur specifically in the direct object position. An example of the structure of a predicted direct object gap is presented in Figure 42.[5]

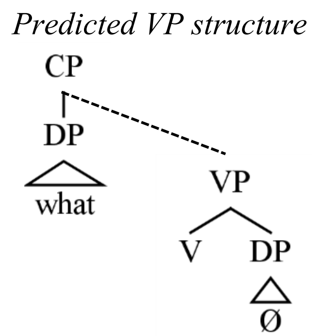



Figure 42. Representation of a direct object gap prediction in filler-gap dependency processing after the filler, *what*, has been provided by the input.[6]

This implementation of structural prediction is compatible with accounts of sentence processing in which the parser relies on language experience when making structure building decisions. A probabilistic parser (e.g., Hale, 2001, 2003; Levy, 2008b) relies on statistical information about the distribution of syntactic structures to make parsing decisions during real time comprehension. The predictions that a probabilistic parser generates about the upcoming input are based on the most probable continuation. These probabilities are calculated from the frequency of the possible structural continuations in the comprehender's previous language experience, i.e., the input distribution.

Thus, a probabilistic explanation for active gap filling relies on a specific structural prediction of the gap position. In filler-gap dependency processing, the

[5] Other levels of predicted representation are also possible (e.g., prediction of the complete structure between the filler and the VP housing the gap), but the exact form of the representation is not relevant for the comparison of these implementations. What is critical for this implementation is that a specific prediction about the gap position is being generated. See Linzen and Jaeger (2015) for further discussion about the depth of predicted syntactic representations.

[6] The gap is denoted by a null constituent Ø for convenience and as a means to remain theory neutral about the actual syntactic status of the gap (a copy, a trace, etc.).

predicted gap position should be the most probable one. This probability is calculated by comparing the frequency of multiple potential gap positions (e.g., subject, direct object, and prepositional object gaps). Accordingly, direct object gaps should only be predicted if they are the most probable. The distributional analysis of adult input (Experiment 2) confirms this; direct object gaps are the most frequent overall and, of the examined post-verbal gap positions, are significantly more frequent than prepositional object gaps.

### 2.1.1 Evidence for and against specific structural predictions

According to a probabilistic parsing account, statistical information about gap positions should directly lead to a direct object gap expectation during filler-gap dependency processing. However, findings from both adults and children provide evidence against the specific structural prediction hypothesis. First, the findings presented in Chapter 3 suggest that adults only adapt their gap predictions based on the input distribution in very limited circumstances. Experiment 3 provides evidence that probabilities play some limited role in the syntactic predictions generated during the real time comprehension of filler-gap dependencies. Within a single experimental environment, exposure to input that alters the baseline probability distribution, i.e., input containing exclusively prepositional object gaps, decreased direct object predictions. However, the probability of a particular gap position is determined in comparison with competing hypotheses about the gap position. If active gap filling is the result of a specific prediction of a direct object gap, then ceasing to predict this gap position should result in an alternative gap position being actively predicted based on the input distribution. Experiment 4 reveals that this is not the case; exposure to prepositional object gaps did not lead to a prediction of this particular gap position.

Experiment 5 also provides evidence that the effect of syntactic expectation adaptation is limited. In this experiment, experience with gap positions was provided in a study separate from that in which adaptation was evaluated. Although participants were exposed to an input distribution identical to that from Experiment 3 (i.e., exclusively prepositional object gaps), they persisted in their direct object gap predictions. I take this as evidence that the effect of language experience does not generalize beyond a very limited context. In this case, that context is a single, self-contained experiment as the effects of language experience do not generalize across studies within a single experimental session (Experiment 3 versus Experiment 5). This lack of generalizability, then, is further evidence against the probabilistic parsing account.

Furthermore, the findings from the studies of children's processing of filler-gap dependencies contradict the specific gap prediction hypothesis. Children are exposed to the correct distribution of gap positions in their input to trigger active gap filling by age 5 (Experiment 2), but even 7-year-olds do not consistently predict a direct object gap when processing *wh*-questions (Experiment 1). Collectively, these results suggest that the input distribution is not sufficient, and perhaps not necessary, for the development of active gap filling. If probabilistic information was sufficient, children should predict direct object gaps by at least 5-years-old.

In addition, the results of the two priming studies (Experiments 6 and 7), which were designed to accelerate the development of active gap filling in 5-year-olds, are particularly striking. Children in the production priming study began reliably predicting direct object gaps in their real time comprehension (Experiment 7). However, these increased direct object gap predictions were only found for the children who produced *wh*-questions with prepositional object gaps. This is the exact opposite of what the specific gap prediction hypothesis and the probabilistic parsing account would predict; increased experience with prepositional object gaps should generate predictions of *prepositional object* gaps, not *direct object* gaps.

Relatedly, children whose experience with filler-gap dependencies was enriched by comprehension of *wh*-questions (Experiment 6) did not begin to predict direct object gaps (i.e., they behaved identically to the 5-year-olds from Experiment 1). This finding also cannot be explained by the probabilistic parsing account. Assuming gap predictions are based on probabilistic information derived from the distribution of gap positions in the input, the position of the predicted gap should reflect that input. This is not the case in Experiment 7; exposure to direct object gaps does not increase 5-year-old's direct object gap predictions. This finding is related to the findings from adult syntactic adaptation in Experiment 4. Though adults were exposed to prepositional object gaps, their gap predictions also did not reflect this input because they did not actively predict prepositional object gaps after experience with them.

Altogether, the findings from this dissertation suggest a fairly limited role for the statistics derived from language experience on the syntactic predictions generated during filler-gap dependency processing. Accordingly, the hypothesis that syntactic predictions about the gap position are the result of specific structural predictions is not supported. The following section details an alternative implementation of active gap filling that is compatible with the developmental findings.

## 2.2 The proposal: Successive gap evaluation

Alternatively, I propose an original implementation that attributes active gap filling to the result of a series of successive gap predictions. In the implementation utilizing specific structural predictions, the presence of a filler in the input triggers the prediction of a gap in a specific structural position (i.e., in the direct object position, see Figure 42). Conversely, the successive gap evaluation implementation suggests that the gap prediction is evaluated at every phrase structure node following the filler until a gap position is located. Syntactically, a filler requires a gap, so the presence of the former leads to an active search for the latter. This search for a gap results in successive predictions that the next phrase in the input will be the gap host, and these predictions are confirmed or rejected at each step of incremental processing (i.e., with each new word in the input) until the gap is located. Thus, instead of a specific prediction about the structural position of the gap, this implementation relies on the structural requirement that a filler must be associated with a gap. This gap is then predicted to be hosted at each successive structural position until this requirement has been met. There are three critical features of this implementation: 1) a gap feature that is associated with the *wh*-phrase, 2) an incremental increase of the activation of this gap feature, and 3) an activation threshold for the triggering of gap prediction. I will address each in turn.

*The gap feature.* In the successive gap evaluation account, the gap prediction generated by the filler is explicitly represented by a gap feature that originates on the *wh*-phrase. This gap feature is inherited by all of the phrase structure nodes between the filler and gap. Each of these nodes represents a potential gap host projection, and a gap prediction associated with each node is evaluated successively. This gap feature representation resembles the representation of long distance dependencies by a GAP feature in generalized phrase structure grammar (GPSG, Gazdar, Klein, Pullum, & Sag, 1985) or a SLASH feature in head-driven phrase structure grammars (HPSG, Pollard & Sag, 1994; see also Bouma, Malouf, & Sag, 2001). In HPSG, for example, fillers are connected to gaps through a series of SLASH features indicating the category of the element required to satisfy the dependency (e.g., NP). These SLASH features are present on each syntactic constituent that intervenes between the head and the tail of the dependency including on the filler itself.

A mechanism for successively passing this gap feature from one node to another is provided by insights from left corner parsing. The left corner algorithm incorporates both top-down and bottom-up information (Abney & Johnson, 1991; Johnson-Laird, 1983; Kimball, 1975; Resnik, 1992). Specifically, the parser pre-builds the structure associated with a compatible but unconfirmed phrase structure rule once it has encountered some evidence for that rule. As an example, consider the left corner parsing algorithm applied to the sentence *John saw Mary* (see Figure 43).

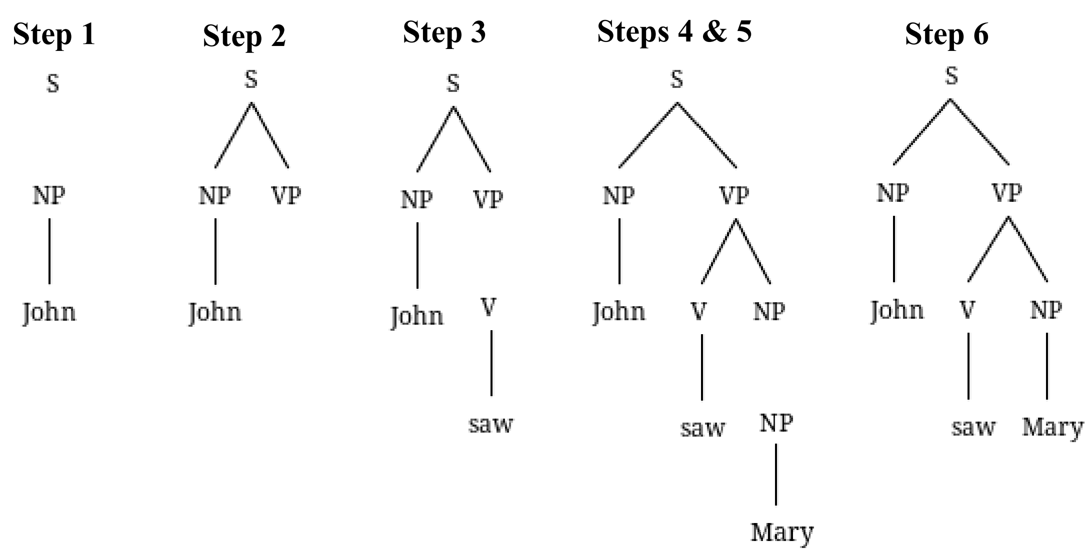



Figure 43. Illustration of left corner parsing. *Step 1:* Bottom-up evidence for the NP *John* is processed. *Step 2:* The left corner parser projects the mother and sister node of the S → NP VP rule. *Step 3:* Bottom-up evidence for the V *saw* is processed. *Step 4:* The mother

and sister nodes of the VP → V NP rule are projected. *Step 5:* Bottom-up evidence for the NP *Mary* is processed. *Step 6:* The full utterance has been processed.

Parsing begins with the top-down assumption that a sentence is being built and, therefore, the phrase structure rule S → NP VP applies. When the bottom-up evidence of an NP is processed, i.e., *John*, the left corner parser projects both the S mother node and the VP sister node, even though there is no bottom-up evidence for a VP. This is a kind of syntactic prediction; the parser pre-builds structure based on evidence in favor of the S → NP VP rule before the bottom-up information in the input can confirm (or refute) that structure. After processing the verb, *saw*, the parser has bottom-up evidence for the VP → V NP rule, and both the V and NP nodes are projected. The prediction of upcoming syntactic nodes on the basis of bottom-up information continues until the entire sentence has been processed.

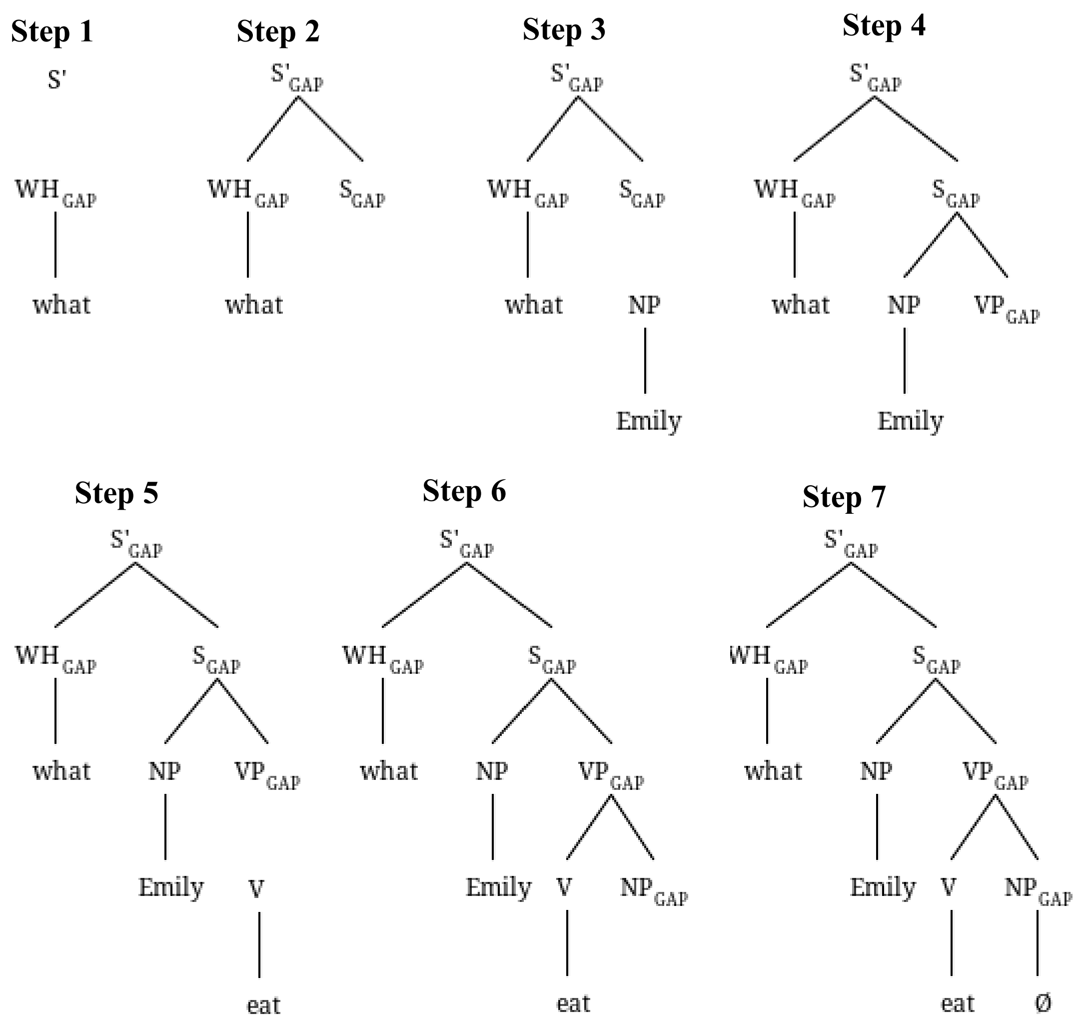
Left corner parsing allows the gap prediction to be projected onto the next predicted structural node by completion of the left corner rule using phrase structure rules incorporating gap features. For example, when a *wh*-phrase with a gap feature is processed, the remainder of the $S'_{GAP} \rightarrow WH_{GAP}\ S_{GAP}$ rule is projected because $WH_{GAP}$ is the left corner of this rule. This leads to a subject gap prediction because the projection of an S node with a gap feature (i.e., $S_{GAP}$) indicates that the gap is predicted to be hosted by this node. Thus, prediction precedes evaluation because the predicted gap host is projected before the input that triggers its evaluation.

*Incremental increase in activation.* When a filler is processed, the gap feature associated with it is activated. I suggest that the activation level of this feature increases as processing continues (for a similar account, see Lewis & Vasishth, 2005). As the gap feature is passed to additional nodes, its activation increases because it is constantly being reactivated until a gap is located. This feature critically allows predictions to emerge late in the processing of an utterance when they are not observed early in the utterance (i.e., children generate prepositional object gap predictions but not direct object gap predictions).

*Activation threshold for prediction.* Finally, I assume there is an activation threshold above which gap prediction and evaluation is triggered. When the activation level of the filler representation or the gap feature is below this threshold, gap predictions are not generated and are not evaluated at the level of the current syntactic node. However, once the activation threshold is crossed, gap prediction and evaluation commences at each successive node.

Both the activation level of the representation and the activation threshold are critical for explaining the developmental data presented in this dissertation. The activation threshold allows gap predictions to be suppressed, while the incremental increase of activation level allows gap predictions to emerge late in the processing of an utterance. These are the key features of children's filler-gap dependency processing.

*Example of successive gap evaluation.* Figure 44 depicts the gap verification process in adults for the question *What did Emily eat__?* according to the successive gap evaluation account. The steps illustrate the passing of the gap feature from one node to another utilizing left corner parsing. The table at the bottom of the figure provides an example of an activation threshold and the incremental increase in the activation of the gap feature as processing proceeds. The activation levels used in this table are not based on any theoretically predicted or experimentally derived values; they are purely for illustrative purposes.




*Activation threshold:* **0.8**

| | **Step 1** | **Step 2** | **Step 3** | **Step 4** | **Step 5** | **Step 6** | **Step 7** |
|---|---|---|---|---|---|---|---|
| **Gap feature activation level** | 0.8 | 0.82 | 0.82 | 0.83 | 0.83 | 0.84 | 0.84 |

Figure 44. Step-by-step representation of the successive gap evaluation for the question 'What did Emily eat?' The table of activation values represent theoretical activation levels. In this example, the activation threshold for gap prediction is 0.8, but this value was chosen randomly to provide a concrete example. *Step 1:* The *wh*-filler is processed and generates a phrase with a [GAP] feature. *Step 2:* The [GAP] feature percolates to the S' node and the S node with a [GAP] feature is predicted. *Step 3:* The NP *Emily* is processed. *Step 4:* The VP node with a [GAP] feature is predicted. *Step 5:* The verb *eat* is processed. *Step 6:* The NP node with a [GAP] feature is predicted. *Step 7:* The question ends, which confirms the direct object gap position.

First, the filler is processed and the gap prediction is indicated by the presence of a gap feature on the *wh*-phrase. The gap feature is activated at 0.8, which is equal to the activation threshold. This means that gap positions will be predicted immediately. The gap feature percolates to the S-bar node as well as to the S node predicted by the $S'_{GAP} \rightarrow WH_{GAP}\ S_{GAP}$ rule. Because the gap feature is inherited by the S-bar node, it is predicted to host the gap at the subject position (see Figure 44, Step 2). Additionally, the activation level of the gap feature increases for each usage, e.g., from 0.8 to 0.82. When the processing of additional input, i.e., the subject NP, excludes the subject gap analysis, the parser transfers the gap feature (which indicates an ongoing gap prediction or search) to the next predicted node, the VP, and a direct object gap is predicted (see Figure 44, Step 4). Again, this additional use of the gap feature increases its activation level further to e.g., 0.83. When the verb is processed, it is inserted into the VP and a direct object gap continues to be predicted (see Figure 44, Step 6). If the utterance ends or the verb is followed by input that is not an NP (e.g., a preposition), the direct object gap prediction is verified and the gap feature is no longer transferred to additional structural nodes (see Figure 44, Step 7). Conversely, if the verb is followed by a direct object NP, then the VP cannot be a host for the gap. Thus, the gap feature continues to transfer and the gap is predicted to be hosted on the next predicted node (e.g., a PP). Crucially, the gap prediction is not only passed to each new structural position, but also evaluated there.[7]

[7] This implementation predicts that the S hosting the subject position should be predicted as a gap host before the VP. There is evidence for subject gap predictions in certain processing environments (Frazier & Flores D'Arcais, 1989; Lee, 2004; Wagers & Pendleton, 2016), but they are notably difficult to find evidence for (Stowe, 1986).

The successive gap evaluation account is quite similar to one of the initial filler-driven accounts of active gap filling, the Active Filler Strategy as presented in (5) (Frazier & Flores D'Arcais, 1989; see also Frazier, 1987; Frazier & Clifton, 1989).

(5) *Active filler strategy:* Assign an identified filler as soon as possible; i.e., rank the option of a gap above the option of a lexical noun phrase within the domain of an identified filler.

According to this strategy, the parser utilizes the syntactic category of the filler in combination with other semantic information (e.g., animacy) to determine possible gap positions. The filler should be associated with the left-most possible position compatible with this category information. For example, the identification of a *wh*-filler like *what* triggers a search for an NP gap position. As the utterance unfolds, the parser will attempt to assign *what* to each successive NP position until the gap is identified.

### 2.2.1 Findings explained by the successive gap evaluation account

The successive gap evaluation account is compatible with the active gap filling effects presented in this dissertation. In particular, I focus on three main findings: 1) the lack of active gap filling at the verb for 5- through 7-year-olds (Chapter 2, Experiment 1), 2) the fact that PO gap production primes active gap filling (Chapter 4, Experiment 7), and 3) the adaptation of gap predictions in adult's filler-gap dependency processing (Chapter 3).

*Experiment 1: Children's lack of active gap filling at the verb.* In Experiment 1, children (5- to 7-year-olds) did not demonstrate active gap filling at the verb. This follows from the combination of an activation level of the gap feature and an activation threshold for successive prediction and evaluation. The initial activation of the gap feature is low for children who do not demonstrate active gap filling. This value is beneath the activation threshold, and thus the activation of the filler-gap representation does not trigger gap predictions.

The finding from the object NP region that 6-year-olds were associating the filler with the direct object gap suggests that the initial activation level is higher for 6-year-olds than for 5-year-olds. The fact that 7-year-olds do not demonstrate active gap filling in this region may also be explained by the initial activation level. As I discussed at the end of Chapter 2, 7-year-olds were generally less engaged with the visual world eye tracking task than the other age groups. The filler-gap representation may have been less activated than during normal comprehension due to this lack of engagement; this less active representation may not have been sufficient to cross the threshold and trigger successive evaluation over the course of the utterance. This is not a case of discontinuous development, but rather the result of the children’s engagement with the task.

The successive gap evaluation account is also able to account for the finding that children of all ages predict a prepositional object gap during the object NP region. The most straightforward explanation is that as the activation level of the gap feature increases during processing, and the threshold for successive evaluation is reached. The prepositional object gap prediction is generated during the object NP region, so the crossing of the activation threshold likely occurs when the object NP is processed. The boost in activation associated with the integration of this phrase is sufficient to cross the threshold and trigger gap predictions. From this point forward during the utterance, children should demonstrate gap predictions. This suggests that were the gap even later in the utterance than in the prepositional object position, children should generate gap predictions at each phrasal node from the point the activation threshold is crossed until the gap is identified.

*Experiment 7: PO gap production primes active gap filling in 5-year-olds.* The successive gap evaluation implementation of active gap filling was proposed in part to account for the findings from Experiment 7. As noted above, children who produced prepositional object gaps began predicting direct object gaps in their real time comprehension of *wh*-questions. Thus, experience with one gap position, prepositional object gaps, led to the subsequent prediction of a *different* gap position, direct object gaps. In the discussion of these findings, I argued that the production of longer filler-gap dependencies, which are more marked and less frequent, primed 5-year-old's representation of the abstract connection between the filler and the gap. In terms of the successive gap evaluation account, this is once again possible thanks to the combination of the activation level of the representation and the activation threshold for gap predictions.

I suggest that the initial activation level of the gap feature is greater during effortful PO-gap production. There is evidence from the priming literature that activation level and effort may be linked. Generally, priming of a more marked (i.e., more rare) structure leads to stronger priming effects. Jaeger and Snider (2013) suggest that this stronger priming is linked to surprisal and prediction error. The less probable structural alternative (e.g., PO datives for the dative alternation; passives) are less likely to be predicted. Thus, there is a large error signal in the form of a large surprisal value when prediction fails. The greater this prediction error, the greater the adjustments to the probability distribution used to generate predictions and the more likely that that structure will be produced in the future.

This greater initial activation is either already above the threshold or crosses the threshold value quickly enough to allow active dependency completion at the verb. These boosted activation levels could affect future parsing decisions. Thanks to the effort required to produce difficult filler-gap dependency structures, 5-year-olds need to activate these representations above their normal baseline level. Consequently, they may have been put into a hyper-parsing mode that affects their parsing decisions for a significant period of time. In such an instance, their parsers may be more willing to make parsing commitments that they would not otherwise. Specifically, this hyper-parsing mode may lead to an increase in the initial activation level of the gap feature that generalizes beyond production to comprehension. Gap predictions should be triggered earlier in the utterance because the amplified initial activation level speeds up the process of crossing the activation threshold.

This account does not necessarily predict long term learning effects, however. The initial activation level is boosted thanks to effortful production, but there is no indication that this amplification is permanent. After some period of time (or change in environment), children may exit hyper-parsing mode and cease to predict direct object gaps during filler-gap dependency processing. Additional work is required to determine the length of this effect and its implications for long-term learning.

*Chapter 3: Syntactic adaptation of gap predictions.* Within a single experimental environment, participants exposed to prepositional object gaps ceased actively completing filler-gap dependencies at the verb (Experiment 3). Findings from

Experiment 4 suggest that this alteration in gap predictions can be attributed to a specific decrease in direct object gap predictions as exposure to prepositional object gaps did not trigger prepositional object gap predictions. Finally, the results of Experiment 5 suggest that distributional information about gap positions does not transfer from one study to another within a single experimental session. Taken together, these results suggest that participants' diminished gap predictions in Experiment 3 were the result of a task-specific processing strategy. If this is true, then successive gap evaluation does not need to account for these findings.

Assuming this adaptation effect is not the result of a task-specific strategy, successive gap evaluation can still explain this effect with an appeal to the probabilities of each gap position. While probabilities are not the basis of gap predictions in this implementation, the fact that probabilistic parsing is a valid explanation for other processing effects (see Levy, 2008) and that effects of statistical learning can be found in adults (e.g., Saffran, Johnson, Aslin, & Newport, 1999) suggests that we continue to collect distributional information about our linguistic experience into adulthood. Thus, I suggest that the processing of a large number of improbable gap positions prompted either an increase in the activation threshold or a decrease in the initial activation level of the gap feature as uncertainty about ones predictions should lead to increased caution about generating those predictions. This increase in threshold or decrease in activation made it more difficult for the activation level of the gap feature to cross the threshold value and, therefore, to trigger the successive evaluation of gap predictions. This is essentially the opposite of what was observed for children in the PO gap production group; rather than triggering successive gap evaluation thanks to boosted activation, extended exposure to PO gaps made it more difficult to trigger this operation.

*Additional cognitive concerns.* This implementation also addresses a computational problem associated with filler-gap dependency processing but not argument structure ambiguity resolution: memory limitations. Because the dependency is not immediately resolved, the filler must be maintained in memory, perhaps in a privileged storage space, until a gap position is identified (Frazier, 1987; Lewis & Vasishth, 2005; Lewis et al., 2006). This factor is not addressed by the probabilistic parsing account, but is important for the investigation of filler-gap dependency processing. In fact, it has been suggested that limitations on the memory system contribute to syntactic predictions (Chen, Gibson, & Wolf, 2005; Frazier, 1987; Gibson, 1998, 2000; Lewis & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006; Wanner & Maratsos, 1978). Early dependency completion may be driven by concerns about the amount of memory being utilized by prediction. In particular, it has been suggested that the maintenance of either the uninterpreted filler or the prediction creates a memory burden. Because memory resources are limited – the set size of working memory has been suggested to be as small as one (McElree, 2001) – the parser is driven to complete dependencies as quickly as possible to make these resources available for other operations.

One source of evidence for the role of memory constraints on filler-gap dependency processing comes from Chen et al. (2005). They hypothesized that predicted syntactic heads were a source of syntactic storage costs. In their Experiments 2 and 3, they examined whether incomplete filler-gap dependencies incur storage costs. In these experiments, reading time of a critical phrase embedded within an incomplete filler-gap dependency (a relative clause, (6a)) was compared to reading time of the same phrase independent of a syntactic prediction of a gap (6b).

(6) a. The claim [which **the cop who the mobster attacked** ignored __] might have affected the jury.
    b. The claim [that **the cop who the mobster attacked** ignored the informant] might have affected the jury.

Reading time at the critical phrase was slower when a gap prediction was being maintained, which Chen et al. interpreted as a storage cost associated with the prediction of a gap.

The successive gap evaluation account incorporates this insight because the gap prediction is evaluated at each syntactic node. Unlike the probabilistic parsing account, which relies on specific structural predictions that do not necessarily result in the shortest possible dependency, successive gap prediction and evaluation ensures that short dependencies are pursued before longer dependencies.

### 2.2.2 Alternative implementations of successive gap evaluation

While the implementation I proposed in this section assumed the presence of a gap feature, it is not necessarily required by the account. Rather, there are several possibilities for how the gap predictions are represented or triggered. The account above assumes an explicit representation of the gap prediction, but this is not required by the proposal. For example, an alternative option is that successive gap evaluation is a general parsing procedure for filler-gap dependencies. In this case, the presence of a filler might automatically trigger this procedure for all phrasal nodes c-commanded by that filler. However, for this version of successive gap evaluation to have the same explanatory power as the version with a gap feature, the representation of the filler itself must include its activation level and perhaps the activation threshold for gap prediction. If the activation of the filler-gap dependency is not represented, then the successive gap evaluation account loses its ability to account for the crucial developmental findings. Further research is required to determine how the prediction is represented.

Additionally, it is possible that the activation level of the gap prediction (however it is represented) does not increase based on the number of nodes housing a gap prediction, but rather on the amount of time that has passed since processing the filler. For example, while the question *Can you tell me what the girl with blond hair was eating the cake with __?* has the same number of potentially gap hosting nodes between the filler and the gap, more time will have elapsed between the processing of the filler and the verb region. It is plausible that children might demonstrate more adult-like direct object gap predictions during the verb if given this additional processing time. This possibility can be tested by lengthening the time between the filler and the verb in the questions from Experiment 1 (visual world eye tracking) by inserting a subject relative clause. If this alteration results in greater direct object gap predictions in children, this would provide evidence that the activation level of the filler-gap dependency increased over time. However, if there is no change to children's active gap filling behavior, this would suggest that the increasing activation level is related to the number of nodes that could potentially host a gap.

## 2.3 Conclusion

Given the evidence against the specific structural prediction implementation, statistical information derived from the input distribution plays only a limited role in generating syntactic predictions during filler-gap dependency processing. Instead, I proposed the successive gap evaluation account, which potentially has ties to GPSG and HPSG implementations of filler-gap dependencies and incorporates insights from researchers who suggest that memory limitations are critical in the processing of long distance dependencies. This account of filler-gap dependency processing provides an explanation for the unexpected effect of producing prepositional object gaps on children's future ability to predict direct object gaps (Experiment 7), as well as the other major findings on filler-gap dependency priming that were presented in this dissertation. I take this as convincing evidence in favor of the successive gap evaluation implementation of active gap filling.

## 3 Future directions

Several lines of future exploration are suggested by the successive gap evaluation implementation of active gap filling and by the results of the experiments presented in this dissertation. I review three of them below.

### 3.1 Application to other long distance dependencies

In theory, the successive gap evaluation implementation should not be limited to filler-gap dependency processing, but rather could apply to all cases of long distance dependency processing. An account of long distance dependency processing that incorporates all long distance dependencies (not just filler-gap dependencies) would be more parsimonious than an account requiring two separate mechanisms. Like filler-gap dependencies, long distance dependencies all consist of a head and a tail, and there is a representational requirement that the head must be associated with the tail.

Thus, other types of long distance dependencies should be revisited in light of this new perspective (e.g., *either…or* coordination: Staub & Clifton, 2006; backward anaphora: Kazanina et al., 2007; Pablos et al., 2015; Van Gompel & Liversedge, 2003; Yoshida et al., 2014). Critically, studies testing this implementation would need to look for a series of predictions about the position of the tail of the dependency. Also, filler-gap dependencies are the only long-distance dependencies that have been studied using real time methodologies (e.g., visual world eye tracking) in children. Additional developmental studies are warranted to determine whether children also demonstrate non-adult-like parsing behaviors with these structures. These studies should also examine whether other long distance dependencies are governed by activation levels and activation thresholds. However, successful application of the successive evaluation account to these other structures would suggest a cohesive account of syntactic prediction in the processing of long distance dependencies.

There is some evidence from the adult literature, however, that at least *either…or* coordination is not a case of successive evaluation and instead involves a specific syntactic prediction. If *either* triggers a successive evaluation of coordination, then there should be evidence of facilitation at all phrasal nodes, but particularly at those syntactic positions where coordination is possible. Staub and Clifton (2006) demonstrated that the presence of *either* not only led to the prediction of a coordinated structure but also that the predicted coordinate will be identical in structure to the first conjunct. In other words, if *either* is attached at the sentential level, sentential coordination is predicted. Conversely, if *either* is attached to a noun phrase, noun phrase coordination is predicted. This suggests that *either* is triggering a specific prediction about the structure of the coordination. If this is a case of specific prediction, then probabilities may govern the syntactic predictions generated by the processing of some long distance dependencies.

Given this potential for specific structural predictions in other long distance dependencies, it is possible that the successive gap evaluation implementation is a special method of evaluating syntactic predictions that applies only to filler-gap dependency processing.

## 3.2 Additional developmental investigations

Further developmental investigations of long distance dependency processing are also warranted. Though Experiment 1 demonstrated that 5-year-olds do not reliably generate a direct object gap prediction while processing filler-gap dependencies, this finding does not entail that children cannot generate adult-like predictions in other structural environments. For example, children have been shown to be capable of adult-like predictive structure selection (Choi & Trueswell, 2010; Kidd et al., 2011; Trueswell et al., 1999). When processing temporary PP-attachment ambiguities like *put the frog on the napkin…in the box* (Trueswell et al., 1999), children and adults predictively select the structure in which the first PP (*on the napkin*) is the destination of the directive from *put* (refer to Figure 1). Although PP-attachment ambiguity resolution is a case of predictive structure selection not predictive structure building, the prediction that is generated is specific; the PP *on the napkin* is predicted to attach to the VP. Thus, children's adult-like processing in this domain suggests that 5-year-olds may be capable of generating specific structural predictions but not capable of successive prediction evaluation. Combining developmental data with studies on the form of the predicted representation in other long distance dependencies can shed light on this issue.

Additionally, previous studies on the offline interpretation of ambiguous biclausal questions (e.g., *Where did Lizzie tell someone _?_ [that she was gonna catch a butterfly*

_?_ ]?) demonstrated that children have the same interpretative preferences as adults (Omaki et al., 2014). Though the filler could be associated with either verb, i.e., where Lizzie told someone and where Lizzie was catching a butterfly are both licit interpretations, adults and children prefer to associate the filler with the first verb linearly, *tell*. Cross-linguistic investigations of the same structure revealed that French and Japanese learning children also patterned with adults (French: Lassotta et al., 2015; Japanese: Omaki et al., 2014). The findings from Japanese speakers confirm that the preference is to complete the dependency in the first *linear* clause (not the main clause); because Japanese is a head-final language, the first verb linearly is within the embedded clause, and it is with this verb that they prefer to interpret the filler.

These findings are in direct contrast with the developmental findings reported in this dissertation in Chapter 2 (Experiment 1). Children seem to be incrementally associating the filler with the first available verb when processing biclausal questions. I argue that this finding could be explained by the successive gap evaluation account detailed above in several ways. First, in addition to being biclausal, these questions are adjunct (e.g., *where*) rather than argument (e.g., *what*) questions. It is reasonable to think that adjunct and argument fillers might have different thresholds for successive evaluation. Misinterpretation of an adjunct gap position is not possible in this structure because both interpretations are grammatical. Conversely, misinterpretation of an argument gap position is possible and would lead to a reanalysis procedure. Given the relative lack of risk in interpreting an adjunct filler-gap dependency, the activation threshold for successive evaluation may be lower; thus, the initial activation of the adjunct filler may be sufficiently above the threshold to trigger successive evaluation, and children actively complete the dependency at the first verb. Further explorations of active dependency completion with argument and adjunct fillers are warranted to test whether this characterization is true.

## 3.3 Naturalistic learning mechanisms for active gap filling

Finally, the 5-year-olds from Experiment 7 who predicted direct object gaps only did so after being exposed to an ideal learning environment: production of marked filler-gap dependency structures. There are two major open questions from this result. First, how do children strengthen the abstract representation of the connection between a filler and a gap in a naturalistic learning environment? Second, at what age does this representation develop? As even 7-year-olds are not reliably predicting direct object gaps, we clearly need to examine the syntactic predictions of older children to discover at what age they are adult-like. Once this is established, we can begin to look at the factors that change between the age of 7 and the age of adult-like prediction.

For example, older children are likely exposed to more varied input than younger children through e.g., learning to read, increased parental confidence in their ability to understand complex structures. This variable input may lead children to attempt to produce more varied input as well, which in turn could lead to a greater number of *wh*-questions productions with gaps in positions other than the direct object. As the production of prepositional object gaps was shown to trigger active gap filling in 5-year-olds, increased production of marked filler-gap dependency structures should theoretically trigger this development outside of the laboratory as well.

# APPENDIX A – TARGET STORIES AND QUESTIONS USED IN EXPERIMENT 1

**Item 1**
Hi, my name is Emily. Today I'd like to eat some cake, but I also need to clean the dishes. Hmm, what should I do first? I think I'm gonna eat the cake, and for that I need a fork. Mmm! That cake was yummy. Now it's time to clean the dishes. I'm gonna need to use a sponge. Oh, those dishes are so clean. I did a great job today.

*Wh*-questions:
    Can you tell me what Emily was eating the cake with __?
    Can you tell me what Emily was washing the dishes with __?
*Yes-No* questions:
    Can you tell me if Emily was eating the cake with the fork?
    Can you tell me if Emily was washing the dishes with the sponge?

**Item 2**
Hi, my name is Sammy, and today I'm helping out my mom in the kitchen. I'm supposed to dry the table and peel some potatoes. Hmm, let me peel the potatoes first in case I make a mess. I'll need a knife to do that. Oh, the potatoes are all peeled. They look great. Now it's time to dry the table. I'm gonna need a paper towel. The table is all dry. I did such a great job helping my mom.

*Wh*-questions:
    Can you tell me what Sammy was peeling the potatoes with __?
    Can you tell me what Sammy was drying the table with __?
*Yes-No* questions:
    Can you tell me if Sammy was peeling the potatoes with the knife?
    Can you tell me if Sammy was drying the table with the paper towel?

**Item 3**
Hi, my name is Rosie, and I'm at the beach. I love playing. Hmm, what can I do? I want to blow up a beach ball and have fun with it. And I also want to build a sandcastle. Hmm, first I think I'll build a sandcastle. I'll need a bucket. Wow! That sound castle looks great. Next it's time to blow up the beach ball. I'll need an air pump to do that. This beach ball looks fantastic! Boy, this is a great day at the beach.

*Wh*-questions:
    Can you tell me what Rosie was building the sandcastle with __?
    Can you tell me what Rosie was blowing up the beach ball with __?
*Yes-No* questions:
    Can you tell me if Rosie was building the sandcastle with the bucket?
    Can you tell me if Rosie was blowing up the beach ball with the air pump?

**Item 4**

Hi, my name is Robbie, and I'm playing up in the attic. There's this trunk I want to dust off and see what's inside. But I also have to light a candle so I can see where I'm going. Hmm, let me light the candle first, I'll need a match. Ahh, there, that's better. Now I can see. Now let me dust off this trunk, I'll need a rag. That trunk is so clean now. Oh yeah, I'm going to have an awesome time in the attic.

*Wh*-questions:

Can you tell me what Robbie was lighting the candle with __?

Can you tell me what Robbie was dusting off the trunk with __?

*Yes-No* questions:

Can you tell me if Robbie was lighting the candle with the match?

Can you tell me if Robbie was dusting off the trunk with the rag?

**Item 5**

My name is Lizzie, and today's my mom's birthday. I have to do something really special for her. I think I'm gonna decorate her package with a bow, and I want to make her some hot chocolate. Hmm, let me make the hot chocolate first. I'll need to use a kettle. Wow! That hot chocolate smells so good! Now it's time to attach this bow to her present. I'll need some glue to do that. Oh! Her present looks so pretty, and I have this great surprise. My mom is going to have a great birthday.

*Wh*-questions:

Can you tell me what Lizzie was making the hot chocolate with __?

Can you tell me what Lizzie was attaching the bow with__?

*Yes-No* questions:

Can you tell me if Lizzie was making the hot chocolate with the kettle?

Can you tell me if Lizzie was attaching the bow with the glue?

**Item 6**

My name is Jimmy, and I'm outside in the yard doing some yard work. I need to cut the grass and chop some wood. Hmm, let me cut the grass first. I'll need a lawn mower. The grass looks fantastic! Now I need to chop the wood so we have some for the fireplace. I need an axe to do that. The wood's all chopped. We're going to have a great fire, and Daddy'll be so proud that I cut all the grass by myself.

*Wh*-questions:

Can you tell me what Jimmy was cutting the grass with __?

Can you tell me what Jimmy was chopping the wood with __?

*Yes-No* questions:

Can you tell me if Jimmy was cutting the grass with the lawn mower?

Can you tell me if Jimmy was chopping the wood with the axe?

**Item 7**

Hi I'm Alice, and I'm out in the backyard. I have to trim the bushes today, and I also really want to catch a butterfly. Well first, I'll trim the bush. I need to use some scissors. Oh, that bush looks so nice! Now it's time to catch that butterfly. I'll need a net. There, I caught him, and he's in a cage. This was a great time outside.

*Wh*-questions:

Can you tell me what Alice was trimming the bush with __?

Can you tell me what Alice was catching the butterfly with __?

*Yes-No* questions:

Can you tell me if Alice was trimming the bush with the scissors?

Can you tell me if Alice was catching the butterfly with the net?

**Item 8**

Hi, my name's Oscar and I'm excited for my grandson to visit this afternoon! I have a couple of things to do before he arrives. I have to sweep the floor and knit a hat for him. First, I'll knit the hat. For that I'll need needles. Wow, this hat looks fantastic! Now it's time to sweep the floor. I'll need a broom for that. The floor looks so clean! My grandson and I will have a great time!

*Wh*-questions:

Can you tell me what Oscar was knitting the hat with __?

Can you tell me what Oscar was sweeping the floor with __?

*Yes-No* questions:

Can you tell me if Oscar was knitting the hat with the needles?

Can you tell me if Oscar was sweeping the floor with the broom?

**Item 9**

Hi my name is Sally and it's the weekend, so it's time to do those chores. I need to paint this mailbox with spray paint and fix my bike. Hmm, I think I'll fix my bike first. I'm gonna need a wrench. Ahh, there, my bike's all better, it looks great. Now it's time to paint the mailbox. I'm gonna need some spray paint. Wow! That mailbox looks fantastic. I've done a great job.

*Wh*-questions:

Can you tell me what Sally was fixing the bike with __?

Can you tell me what Sally was painting the mailbox with __?

*Yes-No* questions:

Can you tell me if Sally was fixing the bike with the wrench?

Can you tell me if Sally was painting the mailbox with the spray paint?

**Item 10**

Hi, my name is Erica and I'm preparing breakfast. I have to fry some pancakes and I have to slice some oranges. Hmm, what should I do first? I think I'll slice the oranges. I'm gonna need a knife. There, those oranges are all sliced. They look fantastic. Now it's time to fry my pancakes. I'm gonna need a pan. Oh, those pancakes look fantastic! Oh, this is gonna be a great breakfast. I can't wait to eat.

*Wh*-questions:

Can you tell me what Erica was slicing the oranges with __?

Can you tell me what Erica was frying the pancakes with __?

*Yes*-*No* questions:

Can you tell me if Erica was slicing the oranges with the knife?

Can you tell me if Erica was frying the pancakes with the pan?

# APPENDIX B – EXPOSURE AND TARGET ITEMS USED IN EXPERIMENT 3

**Exposure Block**

*Direct object gap*

(1) The book that the famous non-fiction author wrote __ about the adventure was named for an explorer.
(2) The quarterly reports that the frazzled government auditor read __ about the accounts were fraudulent.
(3) The minivan that the eccentric old lady drove __ around the city went unnoticed by the highway patrol.
(4) The officer that the hysterically sobbing victim phoned __ about the attack was discussed on the news.
(5) The painting that the infamously successful burglar stole __ from the museum was well guarded.
(6) The national anthem that the school marching band played __ before the game was beautifully performed.
(7) The opponent that the champion lightweight boxer fought __ in the title fight was on the poster for the next fight.
(8) The tree that the highly skilled archer hit __ with an arrow was very far away.
(9) The salmon that the novice sous chef prepared __ for the diners was disliked by the waiters.
(10) The audition that the ambitious, fresh-faced actor performed __ for the director was a huge success.
(11) The shed that the quite, ill-tempered craftsman built __ from old wood was quite unstable.
(12) The caviar that the fabulously wealthy family ate __ as an appetizer was from France.
(13) The wedding dress that the extremely detail-oriented seamstress sewed __ for the bride looked beautiful on the big day.
(14) The cartoon that the giggling blond child drew __ with the crayons was from a coloring book.
(15) The assistant that the experienced circus performer trained __ for the lion taming act was unafraid of anything.
(16) The hotel that the jovial old custodian cleaned __ for twenty-five years was ruined by the financial crisis.
(17) The hot soup that the harried line cook spilled __ on the floor was hard to clean up.
(18) The professional quarterback that the affable sports writer interviewed __ on the morning show was famous for his arm.
(19) The chapter that the easily overwhelmed freshman reviewed __ before the test clarified many concepts.
(20) The rock that the happy, playful girl threw __ into the air was found at the beach.
(21) The cheating student that the irate senior professor lectured __ in front of the class was used as an example.

(22) The leather couch that the young newlywed couple bought __ for their new apartment was perfect for their living room.
(23) The balsamic vinegar that the quirky young foodie poured __ from the bottle was a dark reddish brown.
(24) The country that the renowned jungle explorer discovered __ in South America was lush and beautiful.

*Prepositional Object Gap*

(1) The book that the famous non-fiction author wrote the interesting article about __ was named for an explorer.
(2) The quarterly reports that the frazzled government auditor read the short summary of __ were fraudulent.
(3) The minivan that the hysterically sobbing victim phone the local precinct about __ was discussed on the news.
(4) The officer that the hysterically sobbing victim phoned the local precinct about __ was discussed on the news.
(5) The painting that the infamously successful burglar stole the beautiful watercolor instead of __ was well guarded.
(6) The national anthem that the school marching band played the fight song after __ was beautifully performed.
(7) The opponent that the champion lightweight boxer fought the endless match against __ was on the poster for the next fight.
(8) The tree that the highly skilled archer hit the red bulls eye on __ was very far away.
(9) The salmon that the novice sous chef prepared the special sauce for __ was disliked by the waiters.
(10) The audition that the ambitious, fresh-faced actor performed the long monologue for __ was a huge success.
(11) The shed that the quiet, ill-tempered craftsman built the unique furniture in __ was quite unstable.
(12) The caviar that the fabulously wealthy family ate the delicious lobster after __ was from France.
(13) The wedding dress that the extremely detail-oriented seamstress sewed the tiny crystals onto __ looked beautiful on the big day.
(14) The cartoon that the giggling blond child drew the purple hat onto __ was from a coloring book.
(15) The assistant that the experienced circus performer trained the huge lion with __ was unafraid of anything.
(16) The hotel that the jovial old custodian cleaned the enormous fountains for __ was ruined by the financial crisis.
(17) The hot soup that the harried line cook spilled the minced garlic into __ was hard to fix.
(18) The professional quarterback that the affable sports writer interviewed the college star with __ was famous for his arm.
(19) The chapter that the easily overwhelmed freshman reviewed the quick summary of __ clarified many concepts.
(20) The rock that the happy, playful girl threw the red ball at __ was found at the beach.

(21) The cheating student that the irate senior professor lectured the whole class about __ was used as an example.
(22) The leather couch that the young newlywed couple bought the matching loveseat after __ was perfect for their living room.
(23) The balsamic vinegar that the quirky young foodie poured the extra virgin olive oil into __ was a dark reddish brown.
(24) The country that the renowned jungle explorer discovered the wide river in __ was lush and beautiful.

**Experimental Block**

(1) a. The bill that the notoriously conservative senator wrote the lengthy statement about __ was hurting his popularity.
 b. The bill about which the notoriously conservative senator wrote the lengthy statement __ was hurting his popularity.
(2) a. The documents that the tenacious corporate lawyer read the brief annotations about __ hurt her client's case.
 b. The documents about which the tenacious corporate lawyer read the brief annotations __ hurt her client's case.
(3) a. The convertible that the handsome young businessman drove his wealthy girlfriend in __ was watched by the police.
 b. The convertible in which the handsome young businessman drove his wealthy girlfriend __ was watched by the police.
(4) a. The informant that the decorated police detective phoned the familiar number for __ was missing.
 b. The informant for whom the decorated police detective phoned the familiar number __ was missing.
(5) a. The suitcase that the stealthy, wanted thief stole the precious jewels from __ was full of sentimental items.
 b. The suitcase from which the stealthy, wanted thief stole the precious jewels __ was full of sentimental items.
(6) a. The tournament that the undefeated soccer team played their historic rivals in __ made the entire school cheer.
 b. The tournament in which the undefeated soccer team played their historic rivals __ made the entire school cheer.
(7) a. The dragon that the noble, armor-clad knight fought the incredible battle against __ was discussed by the king's council.
 b. The dragon against which the noble, armor-clad knight fought the incredible battle __ was discussed by the king's council.
(8) a. The ball that the amateur baseball player hit the advancing runner with __ was given to him to keep.
 b. The ball with which the amateur baseball player hit the advancing runner __ was given to him to keep.

(9) a. The poster that the lead gubernatorial candidate prepared the clever slogan for __ turned out well.
   b. The poster for which the lead gubernatorial candidate prepared the clever slogan __ turned out well.

(10) a. The show that the colorfully bedazzled dancers performed the famous routine in __ was very popular.
   b. The show in which the colorfully bedazzled dancers performed the famous routine __ was very popular.

(11) a. The house that the affordable, self-employed contractor built the huge addition on __ was featured in an architecture magazine.
   b. The house on which the affordable, self-employed contractor built the huge addition __ was featured in an architecture magazine.

(12) a. The burger that the beautiful young celebrity ate the curly fries with __ became popular shortly afterward.
   b. The burger with which the beautiful young celebrity ate the curly fries __ became popular shortly afterward.

(13) a. The costume that the creative single mother sewed the googly eyes onto __ looked acceptably spooky on Halloween.
   b. The costume onto which the creative single mother sewed the googly eyes __ looked acceptably spooky on Halloween.

(14) a. The character that the opinionated political cartoonist drew the funny stories about __ made him popular with the studio.
   b. The character about which the opinionated political cartoonist drew the funny stories __ made him popular with the studio.

(15) a. The army spy that the esteemed lieutenant colonel trained the young recruits with __ was a great leader.
   b. The army spy with whom the esteemed lieutenant colonel trained the young recruits ___ was a great leader.

(16) a. The mansion that the pleasant, loyal maid cleaned the wooden floors in __ was quite old.
   b. The mansion in which the pleasant, loyal maid cleaned the wooden floors __ was quite old.

(17) a. The sparkling water that the nervous new waiter spilled the red wine into __ was very expensive.
   b. The sparkling water into which the nervous new waiter spilled the red wine __ was very expensive.

(18) a. The coach that the respected talent scout interviewed the tennis player for __ was well known.
   b. The coach for whom the respected talent scout interviewed the tennis player __ was well known.

(19) a. The evidence file that the irritable federal agent reviewed the multiple notes on __ caused him concern.
   b. The evidence file on which the irritable federal agent reviewed the multiple notes __ caused him concern.

(20) a. The toy car that the rosy-cheeked little boy threw the old blanket over __ was painted blue.

b. The toy car over which the rosy-cheeked little boy threw the old blanket __ was painted blue.

(21) a. The substitute teacher that the stern vice principal lectured the misbehaved students for __ was very grateful for the help.

b. The substitute teacher for whom the stern vice principal lectured the misbehaved students __ was very grateful for the help.

(22) a. The sunscreen that the very pale teenager bought the soothing aloe after __ was a precautionary measure.

b. The sunscreen after which the very pale teenager bought the soothing aloe __ was a precautionary measure.

(23) a. The solution that the careful chemistry student poured the corrosive acid into __ was colorless.

b. The solution into which the careful chemistry student poured the corrosive acid __ was colorless.

(24) a. The treasure that the angry, bearded pirate discovered the weathered map to __ was worth millions of dollars.

b. The treasure to which the angry, bearded pirate discovered the weathered map __ was worth millions of dollars.

# APPENDIX C – TARGET ITEMS USED IN EXPERIMENT 4

(1) a. The scene that the famous stage actor rehearsed __ for the Broadway play was brilliantly directed.
    b. The scene that the famous stage actor who rehearsed for the Broadway play loved __ was brilliantly directed.

(2) a. The horse that the young, athletic jockey rode __ past the leading stallion was expected to do poorly.
    b. The horse that the young, athletic jockey who rode past the leading stallion loved __ was expected to do poorly.

(3) a. The steak that the loud, unflappable uncle cooked __ with the small potatoes was beautifully marbled.
    b. The steak that the loud, unflappable uncle who cooked with the small potatoes bought __ was beautifully marbled.

(4) a. The carcass that the large male lion ate __ by the water's edge was attracting scavengers.
    b. The carcass that the large male lion who ate by the water's edge found __ was attracting scavengers.

(5) a. The statement that the very conservative senator wrote __ about the divisive bill was hurting his popularity.
    b. The statement that the very conservative senator who wrote about the divisive bill composed __ was hurting his popularity.

(6) a. The routine that the colorfully bedazzled dancers performed __ in the Vegas show was very popular.
    b. The routine that the colorfully bedazzled dancers who performed in the Vegas show rehearsed __ was very popular.

(7) a. The suitcase that the stealthy, wanted thief stole __ from the hotel room contained precious jewels.
    b. The suitcase that the stealthy, wanted thief who stole from the hotel room coveted __ contained precious jewels.

(8) a. The recruits that the esteemed lieutenant colonel trained __ with the army spy were young and inexperienced.
    b. The recruits that the esteemed lieutenant colonel who trained with the army spy drilled __ were young and inexperienced.

(9) a. The dragon that the noble, brave knight fought __ with the local peasants was discussed by the king's counsel.
    b. The dragon that the noble, brave knight who fought with the local peasants killed __ was discussed by the king's counsel.

(10) a. The midterms that the grumpy math professor graded __ after the afternoon lecture was very difficult.
    b. The midterms that the grumpy math professor who graded after the afternoon lecture gave __ was very difficult.

(11) a. The director that the award-winning actor interviewed __ with the late night host made a summer blockbuster.
    b. The director that the award-winning actor who interviewed with the late night host admired __ made a summer blockbuster.

(12) a. The concerto that the beautiful first violinist played __ in the orchestra performance was written by Bach.
b. The concerto that the beautiful first violinist who played in the orchestra performance appreciated __ was written by Bach.

(13) a. The pattern that the nice bridal seamstress sewed __ with the industrial machine cost lots of money.
b. The pattern that the nice bridal seamstress who sewed with the industrial machine bought __ cost lots of money.

(14) a. The staff that the tough vice principal lectured __ about the substitute teacher was ineffectual.
b. The staff that the tough vice principal who lectured about the substitute teacher disliked __ was ineffectual.

(15) a. The demonstration that the third grade teacher prepared __ for the new lesson disrupted her normal routine.
b. The demonstration that the third grade teacher who prepared for the new lesson planned __ disrupted her normal routine.

(16) a. The slogan that the lead gubernatorial candidate prepared __ for the campaign speech turned out well.
b. The slogan that the lead gubernatorial candidate who prepared for the campaign speech worried about __ turned out well.

(17) a. The attorney that the decorated police detective phoned __ for the mob informant was missing.
b. The attorney that the decorated police detective who phoned for the mob informant needed __ was missing.

(18) a. The wine that the nervous new waiter spilled __ into the sparkling water was very expensive.
b. The wine that the nervous new waiter who spilled into the sparkling water recommended __ was very expensive.

(19) a. The company that the frustrated, unhappy tenants paid __ for the maintenance man improved the building.
b. The company that the frustrated, unhappy tenants who paid for the maintenance man wanted __ improved the building.

(20) a. The notes that the irritable federal agent read __ about the evidence file caused him concern.
b. The notes that the irritable federal agent who read about the evidence file discovered __ caused him concern.

(21) a. The convertible that the handsome young businessman drove __ past the luxury sedan was watched by the police.
b. The convertible that the handsome young businessman who drove pas the luxury sedan admired __ was watched by the police.

(22) a. The addition that the self-employed contractor built __ on the old house was featured in a magazine.
b. The addition that the self-employed contractor who built on the old house improved __ was featured in a magazine.

(23) a. The room that the pleasant, loyal maid cleaned __ in the stunning mansion was quite old.

b. The room that the pleasant, loyal maid who cleaned in the stunning mansion admired __ was quite old.

(24) a. The politician that the blood-thirsty criminal kidnapped __ for the wealthy CEO was absent during the inquest.

b. The politician that the blood-thirsty criminal who kidnapped for the wealthy CEO despised __ was absent during the inquest.

# APPENDIX D – STORIES AND TARGET ITEMS USED IN EXPERIMENT 5

**Story 1**

*Direct object gap*

Jane recently moved to a new apartment but she needed to decorate it to have everything look the way she wanted. A friend helped her dress the windows in her living room to set the color palette. **The drapes that her friend hung __ from the curtain rod looked great.** She was happy with how the curtains looked, but the apartment still needed work. Jane wanted more furniture to fill the space. First, she decided to focus on her bedroom. **The new furniture that Jane envisioned __ in the bedroom would be painted to match her newly hung drapes.** She thought that would tie the whole apartment together. She began her furniture search on Craigslist. Jane had seen a posting for a bedroom set before she moved, and she decided to buy it. **The nightstand that she bought __ with the dresser was perfect for her new bedroom.** After she brought it into her apartment, she was surprised to find a hidden drawer containing a letter. **The letter that Jane discovered __ inside the secret drawer was very dusty.** Jane couldn't resist reading the letter, but unfortunately it wasn't very interesting at all, so she threw it away.

*Prepositional object gap*

Jane recently moved to a new apartment but she needed to decorate it to have everything look the way she wanted. A friend helped her dress the windows in her living room to set the color palette. **The curtain rod that her friend hung the drapes from __ looked great.** She was happy with how the curtains looked, but the apartment still needed work. Jane wanted more furniture to fill the space. First, she decided to focus on her bedroom. **The bedroom that Jane envisioned the new furniture in __ would be painted to match her newly hung drapes.** She thought that would tie the whole apartment together. She began her furniture search on Craigslist. Jane had seen a posting for a bedroom set before she moved, and she decided to buy it. **The dresser that she bought the nightstand with __ was perfect for her new bedroom.** After she brought it into her apartment, she was surprised to find a hidden drawer containing a letter. **The secret drawer that Jane discovered the letter inside __ was very dusty.** Jane couldn't resist reading the letter, but unfortunately it wasn't very interesting at all, so she threw it away.

**Story 2**

*Direct object gap*

It was a beautiful morning, so Tom the squirrel decided to go on an adventure through town. **An acorn that he hid __ under a fallen branch was his first destination.** He ran to where he thought the branch was, but he couldn't seem to find it. Tom knew that he needed help to solve this mystery. He thought that his cat and dog friends could help him. **The cat that Tom always saw __ with the dog usually knew where to find things.** He went to their house but they weren't there. After walking around for what felt like forever, Tom could only find his chipmunk friend, Patches, to help him. They went to check one of her favorite hiding places to see if any of her treasures were missing too. **A coin that Patches buried __ next to the pine cone wasn't there either.** Why was everything disappearing?! They decided to head back to Tom's house, which they could see in the distance. As they kept walking, more strange things started happening. **The treehouse that Tom built __ beside the log cabin disappeared completely.** All of a sudden, Tom felt a falling sensation but then he jerked awake only to find that it was a beautiful morning and that all was right with the world. It turned out he had been dreaming all along.

*Prepositional object gap*
It was a beautiful morning, so Tom the squirrel decided to go on an adventure through town. **A fallen branch that he hid an acorn under __ was his first destination.** He ran to where he thought the branch was, but he couldn't seem to find it. Tom knew that he needed help to solve this mystery. He thought that his cat and dog friends could help him. **The dog that Tom always saw the cat with __ usually knew where to find things.** He went to their house but they weren't there. After walking around for what felt like forever, Tom could only find his chipmunk friend, Patches, to help him. They went to check one of her favorite hiding places to see if any of her treasures were missing too. **The pine cone that Patches buried a coin next to __ wasn't there either.** Why was everything disappearing?! They decided to head back to Tom's house, which they could see in the distance. As they kept walking, more strange things started happening. **The log cabin that Tom built the treehouse beside __ disappeared completely.** All of a sudden, Tom felt a falling sensation but then he jerked awake only to find that it was a beautiful morning and that all was right with the world. It turned out he had been dreaming all along.

**Story 3**
*Direct object gap*
Jake was really hungry and wanted to try one of the new restaurants in his neighborhood, but he didn't know which one to go to. **The review that he read __ about the restaurant's menu helped him make his decision.** Jake was excited to see that the restaurant only served hamburgers and that many of the burgers received four star ratings from the reviewers. Just as his mouth started to water, Jake remembered the last time he ate a hamburger. **The food poisoning that Jake got __ from the hamburger was still painful to recall.** So, Jake knew he had to change his plans and started looking for inspiration. He searched through his junk drawer, where he found a number of things that he had forgotten about. **The invitation to this year's block party that he found __ under the take-out menus gave him an idea.** Jake decided to call all of his neighbors and have them over for a huge take-out feast, which became a yearly neighborhood tradition. **The tradition that they started __ with the feast was talked about forever.** Everyone loved the opportunity to come together as a neighborhood, and, best of all, no one had to cook.

*Prepositional object gap*
Jake was really hungry and wanted to try one of the new restaurants in his neighborhood, but he didn't know which one to go to. **The restaurant's menu that he read a review about __ helped him make a decision.** Jake was excited to see that the restaurant only served hamburgers and that many of the burgers received four star ratings from the

reviewers. Just as his mouth started to water, Jake remembered the last time he ate a hamburger. **The hamburger that Jake got the food poisoning from __ was still painful to recall.** So, Jake knew he had to change his plans and started looking for inspiration. He searched through his junk drawer, where he found a number of things that he had forgotten about. **The take-out menus that he found the invitation to this year's block party under __ gave him an idea.** Jake decided to call all of his neighbors and have them over for a huge take-out feast, which became a yearly neighborhood tradition. **The feast that they started the tradition with __ was talked about forever.** Everyone loved the opportunity to come together as a neighborhood and, best of all, no one had to cook.

**Story 4**

*Direct object gap*

George woke up late on his first day at his new job! **The alarm that he programmed __ on his phone didn't work properly.** George went into his closet to pick out a fresh shirt to wear. To his dismay, his favorite shirt was in poor condition. **The wrinkles that George found __ on the shirt needed to be ironed.** After ironing his shirt thoroughly, George ran downstairs to eat breakfast. His roommate, Dan, offered to make him coffee. **The hazelnut creamer that Dan poured __ into the coffee had a pleasant aroma.** Energized, George scarfed down his breakfast and hurried out the door to catch a bus. Heavy rain made the streets muddy and the visibility was very poor. **The road that the bus driver saw __ through the window needed to be cleaned.** The bus finally pulled up to George's stop and he jumped out of his seat to make his way to the office. Luckily, George made it to work just in time.

*Prepositional object gap*

George woke up late on his first day at his new job! **The phone that he programmed the alarm on __ didn't work properly.** George went into his closet to pick out a fresh shirt to wear. To his dismay, his favorite shirt was in poor condition. **The shirt that George found the wrinkles on __ needed to be ironed.** After ironing his shirt thoroughly, George ran downstairs to eat breakfast. His roommate, Dan, offered to make him coffee. **The coffee that Dan poured the hazelnut creamer into __ had a pleasant aroma.** Energized, George scarfed down his breakfast and hurried out the door to catch a bus. Heavy rain made the streets muddy and the visibility was very poor. **The windshield that the bus driver saw the road through __ needed to be cleaned.** The bus finally pulled up to George's stop and he jumped out of his seat to make his way to the office. Luckily, George made it to work just in time.

**Story 5**

*Direct object gap*

Kelly wanted to watch a movie. She loves soccer and plays on a team, so a newly released documentary about the real life of a professional soccer player caught her eye immediately. **The review that Kelly saw __ about the movie was written by a close friend of the real life main character.** The movie told the story of a girl named Paula and her exciting soccer career. She was very good, so she got to play in many international tournaments where she was able to meet coaches and new friends including girls from Spain and London. **The other soccer players that Paula met __ through the coaches were widely admired.** The other girls helped her improve her game and they worked together every day to help her get better. **The skills that she learned __ from the team practices were very difficult.** The movie ended with Paula becoming a part of the Olympic team and ultimately winning the gold medal at the Games. **The medal that the US team won __ in the championship game made all of the American fans cheer.** Kelly really enjoyed the movie. She ended up going to see the movie again with all of her teammates as inspiration before their own championship game!

*Prepositional object gap*
Kelly wanted to watch a movie. She loves soccer and plays on a team, so a newly released documentary about the real life of a professional soccer player caught her eye immediately. **The movie that Kelly saw the review about __ was written by a close friend of the real life main character.** The movie told the story of a girl named Paula and her exciting soccer career. She was very good, so she got to play in many international tournaments where she was able to meet coaches and new friends including girls from Spain and London. **The coaches that Paula met the other soccer players through __ were widely admired.** The other girls helped her improve her game and they worked together every day to help her get better. **The team practices that she learned the skills from __ were very difficult.** The movie ended with Paula becoming a part of the Olympic team and ultimately winning the gold medal at the Games. **The championship game that the US team won the medal in __ made all of the American fans cheer.** Kelly really enjoyed the movie. She ended up going to see the movie again with all of her teammates as inspiration before their own championship game!

**Story 6**
*Direct object gap*
Joe decided to take a jog after a stressful day's work. **A path that Joe discovered __ through a park seemed to be the most scenic route.** After running for a while, Joe looked for a nice place to rest. He saw a tree lined stream near an old bridge in the distance. **The shady spot that Joe found __ along the cool stream provided relief on such a hot day.** Feeling recharged, Joe felt it was time to power through to the end of his jog. It was then that Joe heard a little girl laughing. He turned to find the source of the sound. **The puppy that the little girl chased __ around the mother looked very happy.** The sight made Joe smile, and he ran on, feeling better after such a long day. He decided to continue his jog through a tunnel near the park. **The mural that he saw __ in the tunnel was newly restored.** Joe was very happy to see that people were looking after the park and enjoying it on such a beautiful day. He stopped at a food cart at the exit to the park to grab a bottle of water. Joe was tired after such a long run, but felt a lot less stressed and was certainly thankful for that.

*Prepositional object gap*

Joe decided to take a jog after a stressful day's work. **The park that Joe discovered a path through __ seemed to be the most scenic route.** After running for a while, Joe looked for a nice place to rest. He saw a tree lined stream near an old bridge in the distance. **The cool stream that Joe found the shady spot along __ provided relief on such a hot day.** Feeling recharged, Joe felt it was time to power through to the end of his jog. It was then that Joe heard a little girl laughing. He turned to find the source of the sound**. The mother that the little girl chased the puppy around __ looked very happy.** The sight made Joe smile, and he ran on, feeling better after such a long day. He decided to continue his jog through a tunnel near the park. **The tunnel that he saw the mural in __ was newly restored.** Joe was very happy to see that people were looking after the park and enjoying it on such a beautiful day. He stopped at a food cart at the exit to the park to grab a bottle of water. Joe was tired after such a long run, but felt a lot less stressed and was certainly thankful for that.

**Story 7**

*Direct object gap*

Recently a little boy had a birthday, so he sent his friends invitations. Later, his mom wrote an email to remind their parents to RSVP. **The email that the boy's mom wrote __ about the invitations made the party sound great.** The little boy's friends were so excited that they all agreed to come! On the day of the party, the boy and his mom spent all morning setting up for the guests. **The decorations that they hung __ with the tape matched the party's theme.** All of the guests arrived on time and, best of all, they were carrying gifts! The boy's mother told him not to open the presents yet. She encouraged him to be a good host and suggested that he serve his guests refreshments. **The drinks that the boy distributed __ with the snacks hit the spot!** After enjoying the refreshments, the guests at the party decided to play some games, and a ball was thrown mistakenly into the kitchen. **The special icing that the mother made __ for the cake was ruined.** All of the boys' friends felt horrible for ruining the party, but luckily the birthday boy's mom had thought ahead, and pulled ice cream out of the freezer to save the day!

*Prepositional object gap*

Recently a little boy had a birthday, so he sent his friends invitations. Later, his mom wrote an email to remind their parents to RSVP. **The invitations that the boy's mom wrote the email about __ made the party sound great.** The little boy's friends were so excited that they all agreed to come! On the day of the party, the boy and his mom spent all morning setting up for the guests. **The tape that they hung the decorations with __ matched the party's theme.** All of the guests arrived on time and, best of all, they were carrying gifts! The boy's mother told him not to open the presents yet. She encouraged him to be a good host and suggested that he serve his guests refreshments. **The snacks that the boy handed out the drinks with __ hit the spot!** After enjoying the refreshments, the guests at the party decided to play some games, and a ball was mistakenly thrown into the kitchen. **The cake that the mother made the special icing for __ was ruined.** All of the boy's friends felt horrible for ruining the party, but luckily the birthday boy's mom had thought ahead, and pulled ice cream out of the freezer to save the day!

**Story 8**

*Direct object gap*

One day, a young couple, John and Mary, decided to drive to the mall. They searched for a map and got in their car. **The route that the couple found __ with the map was convenient.** When John and Mary got to the mall, they ran into Bill, an old friend from college who was known for always telling funny stories, and he did not let them down! **The punchline that Bill told __ to the joke was hilarious.** After talking with Bill for about an hour, John and Mary realized that they were hungry, so the couple decided to go to the food court. Mary wanted something to eat, and a drink to help wash it down. When they finally got to the food court, Mary saw something very disappointing! **The soda that she wanted __ with the meal was expensive.** She ended up deciding on her second choice, which was much cheaper. After an underwhelming lunch, the young couple headed back to the stores they passed on their way to the food court where they had seen ads for clothes with special deals. **Unfortunately, the deals that they saw __ for the clothes were gone.** John and Mary were so disappointed that they left the mall and went to see a movie instead.

*Prepositional object gap*

One day, a young couple, John and Mary, decided to drive to the mall. They searched for a map and got in their car. **The map that the couple found the route with __ was convenient.** When John and Mary got to the mall, they ran into Bill, an old friend from college who was known for always telling funny stories, and he did not let them down! **The joke that Bill told the punchline to __ was hilarious.** After talking with Bill for about an hour, John and Mary realized that they were hungry, so the couple decided to go to the food court. Mary wanted something to eat, and a drink to help wash it down. When they finally got to the food court, Mary saw something very disappointing! **The meal that she wanted the soda with __ was expensive.** She ended up deciding on her second choice, which was much cheaper. After an underwhelming lunch, the young couple headed back to the stores they passed on their way to the food court where they had seen ads for clothes with special deals. **Unfortunately, the clothes that they saw the deals for __ were gone.** John and Mary were so disappointed that they left the mall and went to see a movie instead.

**Story 9**

*Direct object gap*

Last week a pair of robbers strolled into a bank, and handed a teller a note demanding money. **The amount that the teller read off __ of the note surprised her because they only wanted a small sum of money.** Not knowing what else to do she handed over the money and the robbers fled. However, there were police officers waiting for them around the corner. The officers turned on their lights and started to chase them. **The robbers that the police officers chased __ in the cars were held up by a large group of pedestrians.** The robbers made it to their getaway car but they were having trouble getting in. Before they went into the bank, the robbers had hidden the key near the car.

**But, the key that the one robber had stored __ in the little box was missing!** Since the robbers couldn't get into their car, the police officers were quickly approaching them. They had the robbers surrounded. **The plan that the robbers carried out __ for the heist had failed.** The cops were able to arrest the robbers and put them in jail for a long time.

*Prepositional object gap*
Last week a pair of robbers strolled into a bank, and handed a teller a note demanding money. **The note that the teller read the amount off of __ surprised her because they only wanted a small sum of money.** Not knowing what else to do she handed over the money and the robbers fled. However, there were police officers waiting for them around the corner. The officers turned on their lights and started to chase them. **The cars that the police officers chased the robbers in __ were held up by a large group of pedestrians.** The robbers made it to their getaway car but they were having trouble getting in. Before they went into the bank, the robbers had hidden the key near the car. **But, the little box that the one robber had stored the key in __ was missing!** Since the robbers couldn't get into their car, the police officers were quickly approaching them. They had the robbers surrounded. **The heist that the robbers carried out the plan for __ had failed.** The officers were able to arrest the robbers and put them in jail for a long time.

**Story 10**
*Direct object gap*
Jill and Justin planned to spend a day exploring New York City. Over the past few weeks, they had been reading all the information they could find about things to do there. **The blog post that their friend wrote __ about the newspaper article gave great tips about the most popular attractions in the city.** They decided that they definitely wanted to go shopping in Times Square and that in the evening they would see a Broadway play. They left on the train the next morning. After they arrived in New York, they made their way to Times Square. **The crowds that they encountered __ in the shops were enormous.** They looked around for a while, but decided not to buy anything so that they would not have to carry bags with them the rest of the day. After all of their time in the crowds, Jill and Justin were exhausted and they decided to find a place where they could eat lunch. **The delicious sandwich that Jill discovered __ on the deli's menu was much more expensive than she expected.** The couple decided to splurge, though, since it was their first time in the city. Then, they walked through Central Park until it was time for them to take their seats for the show. **The famous actress that the couple watched __ in the musical made them want to come back and see a Broadway performance again.** Jill and Justin were sad to leave after such an exciting day in the city.

*Prepositional object gap*
Jill and Justin planned to spend a day exploring New York City. Over the past few weeks, they had been reading all the information they could find about things to do there. **The newspaper article that their friend wrote the blog post about __ gave great tips about the most popular attractions in the city.** They decided that they definitely

wanted to go shopping in Times Square and that in the evening they would see a Broadway play. They left on the train the next morning. After they arrived in New York, they made their way to Times Square. **The shops that they encountered the crowds in __ were enormous.** They looked around for a while, but decided not to buy anything so that they would not have to carry bags with them the rest of the day. After all of their time in the crowds, Jill and Justin were exhausted and they decided to find a place where they could eat lunch. **The deli's menu that Jill discovered the delicious sandwich on __ was much more expensive than she expected.** The couple decided to splurge, though, since it was their first time in the city. Then, they walked through Central Park until it was time for them to take their seats for the show. **The musical that the couple watched the famous actress in __ made them want to come back and see a Broadway performance again.** Jill and Justin were sad to leave after such an exciting day.

**Story 11**

*Direct object gap*

There once was a kingdom ruled by a queen and her daughter who never left the castle. The princess sometimes dreamt of traveling, and she wrote crazy adventure stories in a private diary held in a secret box. **The diary that the princess hid __ in the box had a supposedly unbreakable lock.** But one day her mother found the box and, intrigued by the secretive lock, broke into it. She was heartbroken by the thought of her daughter leaving, so she decided to trap her daughter in a tower of the castle. **The princess that the queen locked __ in the tower was hidden from the rest of the kingdom.** The tower was cold and dark and wet. The princess decided to send a note to her mother on an empty breakfast tray left for her by a servant. **The note that the servant delivered __ on the dish went straight to the queen.** When she saw the note, she realized how unhappy her daughter was. She decided to let the princess leave the tower, and even the kingdom! The princess decided to take advantage of her mother's kindness and traveled far and wide. **The new experiences that she enjoyed __ on the adventures were amazing!**

*Prepositional object gap*

There once was a kingdom ruled by a queen and her daughter who never left the castle. The princess sometimes dreamt of traveling, and she wrote crazy adventure stories in a private diary held in a secret box. **The box that the princess hid the diary in __ had a supposedly unbreakable lock.** But one day her mother found the box and, intrigued by the secretive lock, broke into it. She was heartbroken by the thought of her daughter leaving, so she decided to trap her daughter in a tower of the castle. **The tower that the queen locked the princess in __ was hidden from the rest of the kingdom.** The tower was cold and dark and wet. The princess decided to send a note to her mother on an empty breakfast tray left for her by a servant. **The dish that the servant delivered the note on __ went straight to the queen.** When she saw the note, she realized how unhappy her daughter was. She decided to let the princess leave the tower, and even the kingdom! The princess decided to take advantage of her mother's kindness and traveled far and wide. **The adventures that she enjoyed the new experiences on __ were amazing!**

**Story 12**

*Direct object gap*

Anna and Seth had plans to attend their city orchestra's performance on Saturday night at the world renowned concert hall. The building had recently undergone major renovations so the couple was equally excited to see how they had turned out. **The performance that they saw __ in the hall had been advertised throughout the city.** On the program that night was a symphony by Mozart and Seth's favorite piece, the violin concerto by Beethoven. For the concerto, the orchestra welcomed a special guest: a famous violinist. **The solo that the violinist played __ in the piece was met with a standing ovation from the audience.** Seth wanted the violinist's autograph after the performance was over. He bought one of her CDs and asked her to sign it. **The autograph that the musician signed __ on the CD immediately became a precious piece of memorabilia for Seth.** It was a wonderful night at the orchestra! The next week, Seth was reading the newspaper and saw an article about the concert hall. **The Mozart symphony that the orchestra performed __ in the concert received rave reviews in the city newspaper.**

*Prepositional object gap*

Anna and Seth had plans to attend their city orchestra's performance on Saturday night at the world renowned concert hall. The building had recently undergone major renovations so the couple was equally excited to see how they had turned out. **The hall that they saw the performance in __ had been advertised throughout the city.** On the program that night was a symphony by Mozart and Seth's favorite piece, the violin concerto by Beethoven. For the concerto, the orchestra welcomed a special guest: a famous violinist. **The piece that the violinist played the solo in __ was met with a standing ovation from the audience.** Seth wanted the violinist's autograph after the performance was over. He bought one of her CDs and asked her to sign it. **The CD that the musician signed the autograph on __ immediately became a precious piece of memorabilia for Seth.** It was a wonderful night at the orchestra! The next week, Seth was reading the newspaper and saw an article about the concert hall. **The concert that the orchestra performed the Mozart symphony in __ received rave reviews in the city newspaper.**

**Target Items**

(1) a. The book that the author wrote thoughtfully about __ was named for an explorer.
    b. The city that the author wrote thoughtfully about __ was named for an explorer.

(2) a. The quarterly reports that the auditor read extensively about __ were the center of a major scandal.
    b. The bank tellers that the auditor read extensively about __ were the center of a major scandal.

(3) a. The officer that the victim phoned immediately about __ was discussed on the news.
    b. The assault that the victim phoned immediately about __ was discussed on the news.

(4) a. The suitcase that the thief stole discreetly from __ was full of precious jewels.
    b. The store that the thief stole discreetly from __ was full of precious jewels.

(5) a. The opponents that the boxer fought passionately with __ were on the poster for the next fight.
b. The gloves that the boxer fought passionately with __ were on the poster for the next fight.

(6) a. The introductory material that the professor taught regularly about __ was a favorite among the students.
b. The national monument that the professor taught regularly about __ was a favorite among the students.

(7) a. The hotel that the custodian cleaned diligently for __ was ruined by the financial crisis.
b. The millionaire that the custodian cleaned diligently for __ was ruined by the financial crisis.

(8) a. The tennis player that the sports writer interviewed eagerly about __ was the topic of a new book.
b. The unexpected victory that the sports writer interviewed eagerly about __ was the topic of a new book.

(9) a. The substitute teacher that the principal lectured sternly about __ was ineffectual.
b. The standardized test that the principal lectured sternly about __ was ineffectual.

(10) a. The maintenance man that the management company paid reluctantly for __ improved the building.
b. The plumbing work that the management company paid reluctantly for __ improved the building.

(11) a. The minivan that the old lady drove slowly past __ went unnoticed by the highway patrol.
b. The accident that the old lady drove slowly past __ went unnoticed by the highway patrol.

(12) a. The ballad that the country star sang mournfully about __ was the topic of a radio interview.
b. The lover that the country star sang mournfully about __ was the topic of a radio interview.

(13) a. The tango that the performer danced energetically in __ was fantastic.
b. The outfit that the performer danced energetically in __ was fantastic.

(14) a. The textbook that the freshman reviewed casually with __ was on the desk.
b. The highlighter that the freshman reviewed casually with __ was on the desk.

(15) a. The wedding dress that the seamstress sewed diligently for __ looked beautiful on the big day.
b. The blushing bride that the seamstress sewed diligently for __ looked beautiful on the big day.

(16) a. The lesson that the teacher prepared hurriedly for __ disrupted her normal routine.
b. The blizzard that the teacher prepared hurriedly for __ disrupted her normal routine.

(17) a. The executive that the criminal kidnapped cruelly for __ was absent during the investigation.
b. The syndicate that the criminal kidnapped cruelly for __ was absent during the investigation.

(18) a. The supper that the cook prepared skillfully for __ was disliked by the waiters.
b. The client that the cook prepared skillfully for __ was disliked by the waiters.

(19) a. The team that the athlete trained endlessly for __ was covered by the local newspaper.
b. The match that the athlete trained endlessly for __ was covered by the local newspaper.

(20) a. The lady that the designer dressed elegantly for __ was thought to be very important.
b. The party that the designer dressed elegantly for __ was thought to be very important.

(21) a. The consultant that the man phoned hurriedly about __ was mentioned by the CEO.
b. The equipment that the man phoned hurriedly about __ was mentioned by the CEO.

(22) a. The plaque that the tourists read carefully about __ was photographed by the group.
b. The castle that the tourists read carefully about __ was photographed by the group.

(23) a. The research team that the biologist instructed intensely about __ had been highly productive.
b. The bacterial strain that the biologist instructed intensely about __ had been highly productive.

(24) a. The general that the soldier killed mercilessly for __ was conquered by the opponent.
b. The country that the soldier killed mercilessly for __ was conquered by the opponent.

# APPENDIX E – TARGET QUESTIONS USED IN EXPERIMENT 6 AND EXPERIMENT 7

**Draw**
*Direct object*
What was the girl drawing __ with the pencil?
What was the girl drawing __ with the marker?
What was the girl drawing __ with the crayon?
What was the girl drawing __ with the colored pencils?
What was the girl drawing __ with the pen?

*Prepositional object*
What was the girl drawing the house with __?
What was the girl drawing the rocket ship with __?
What was the girl drawing the cat with __?
What was the girl drawing the butterfly with __?
What was the girl drawing the frog with __?

**Wash**
*Direct object*
What was the boy washing __ with the brush?
What was the boy washing __ with the bucket?
What was the boy washing __ with the towel?
What was the boy washing __ with the sprinkler?
What was the boy washing __ with the sponge?

*Prepositional object*
What was the boy washing the scooter with __?
What was the boy washing the car with __?
What was the boy washing the mailbox with __?
What was the boy washing the dog with __?
What was the boy washing the wagon with __?

**Collect**
*Direct object*
What was the girl collecting __ with the cup?
What was the girl collecting __ with the jar?
What was the girl collecting __ with the paper bag?
What was the girl collecting __ with the box?
What was the girl collecting __ with the basket?

*Prepositional object*
What was the girl collecting the ladybugs with __?
What was the girl collecting the fireflies with __?
What was the girl collecting the caterpillars with __?
What was the girl collecting the leaves with __?
What was the girl collecting the strawberries with __?

**Water**
*Direct object*
What was the boy watering __ with the yellow watering can?
What was the boy watering __ with the water gun?
What was the boy watering __ with the spray bottle?
What was the boy watering __ with the hose?
What was the boy watering __ with the red watering can?

*Prepositional object*
What was the boy watering the tulips with __?
What was the boy watering the bush with __?
What was the boy watering the tomatoes with __?
What was the boy watering the sunflowers with __?
What was the boy watering the baby tree with __?

**Cook**
*Direct object*
What was the girl cooking __ with the oven?
What was the girl cooking __ with the microwave?
What was the girl cooking __ with the fire?
What was the girl cooking __ with the grill?
What was the girl cooking __ with the pot?

*Prepositional object*
What was the girl cooking the turkey with __?
What was the girl cooking the egg with __?
What was the girl cooking the hot dog with __?
What was the girl cooking the hamburger with __?
What was the girl cooking the spaghetti with __?

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# VITA

Emily Atkinson was born in Pittsburgh, Pennsylvania on August 13, 1987. In May 2009, Emily graduated from Georgetown University in Washington, DC, with Bachelor of Arts degrees in Psychology (with honors) and Linguistics. The following summer (August 2010), she received a Master's of Sciences in Linguistics with a focus on General Linguistics, also from Georgetown University. Her Master's Research Project examined children's overgeneralizations of the causative. In September 2011, Emily began her Ph.D. program in Cognitive Science at Johns Hopkins University. While at JHU, she was advised by Akira Omaki. Her research examines how the sentence processing mechanisms develop with a special focus on children's real time interpretation of filler-gap dependencies (e.g., *wh*-questions). She completed the requirements for the degree of Doctor of Philosophy in September 2016.